THE SNELLIUS-EXPEDITION

IN THE EASTERN PART OF THE NETHERLANDS EAST-INDIES 1929-1930

UNDER LEADERSHIP OF
P. M. VAN RIEL
DIRECTOR OF THE AMSTERDAM BRANCH OFFICE OF THE
ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE

VOL. II

OCEANOGRAPHIC RESULTS

PART 2

SOUNDINGS AND BATHYMETRIC CHARTS

CHAPTER I

DEPTH DETERMINATIONS

BY

F. PINKE
COMMANDER OF HR. M. S. „WILLEBRORD SNELLIUS"

1935

TO BE OBTAINED OF THE PRINTERS AND PUBLISHERS
E. J. BRILL — LEIDEN

SNELLIUS-EXPEDITIE

WETENSCHAPPELIJKE UITKOMSTEN DER SNELLIUS-EXPEDITIE

ONDER LEIDING VAN

P. M. VAN RIEL

DIRECTEUR VAN DE FILIAALINRICHTING VAN HET KONINKLIJK NEDERLANDSCH METEOROLOGISCH INSTITUUT TE AMSTERDAM

VERZAMELD IN HET OOSTELIJKE GEDEELTE VAN NEDERLANDSCH OOST-INDIË AAN BOORD VAN H. M. WILLEBRORD SNELLIUS

ONDER COMMANDO VAN

F. PINKE

LUITENANT TER ZEE DER 1e KLASSE

1929–1930

UITGEGEVEN DOOR DE MAATSCHAPPIJ TER BEVORDERING VAN HET NATUURKUNDIG ONDERZOEK DER NEDERLANDSCHE KOLONIËN EN HET KONINKLIJK NEDERLANDSCH AARDRIJKSKUNDIG GENOOTSCHAP

GEDRUKT DOOR EN TE VERKRIJGEN BIJ

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A. DEPTH

a. DEPTH.

By the depth of the sea at a certain spot is understood the distance from the surface of the sea, measured perpendicularly, to the point of the sea bottom lying under that spot. Since this distance varies with the tide, the depths given on charts are calculated from a certain level of the sea surface; the depth soundings have to be adjusted by the tide reduction.

This reduction was not applied to the soundings taken by the Snellius expedition, for two reasons, either of which in itself is already sufficient. In the first place the reduction could only be approximated — and even then only at the cost of much extra work — so roughly that often it would be more guesswork than anything else. In the second place the tide reduction is only small compared with the errors in measurement for which no correction could be made.

b. DEPTH FIGURES.

A depth figure on the Snellius deep-sea chart indicates, as is also the case on other charts, the depth expressed in metres at the spot in the middle of the depth figure. A depth figure is based on determination of depth and determination of position, neither of which will be absolutely correct.

c. ABSOLUTE ERROR OF THE DEPTH FIGURE.

This error can be indicated in two ways. It may be expressed by the number of metres by which the depth indicated is in error at the spot indicated by the middle of the depth figure, but it may also be indicated by the distance that the given depth figure has to be removed in the direction perpendicular to the depth line in order to be correct. The first method will be most used over flat, horizontal sea-floor, and the second method over steeply sloping bottom.

d. RELATIVE ERROR OF THE DEPTH FIGURE.

It is not always desirable to take the absolute error into account. Later on it will be seen that the deep echo soundings of the Snellius are affected by a constant error of 35 metres, for which no correction has been made, and that also the wire line soundings shown on the Snellius deep-sea chart are on the average too large by about the same amount. On the Snellius deep-sea chart the sea bottom, at depths greater than a few hundred metres, is thus *on the whole* 35 metres too deep. For comparison of these depths one with the other this error of 35 metres may be disregarded.

If position bearings in the vicinity of an island have been taken with reference to that island and the position of that island itself is not correct, as is presumed to be the case with Sibutu, then all the soundings in the vicinity of that island are affected by the same error in position. In many cases when considering the soundings in that neighbourhood it will be of no influence if that constant error is ignored.

B. WIRE SOUNDINGS

a. APPARATUS.

Except for a few shallow soundings, which were taken with the Kelvite sounding machine, the wire soundings were taken with a large Lucas sounding apparatus. The general arrangement of such an apparatus may be presumed to be known; particulars of the apparatus, its place and the sounding wires used are dealt with in Volume I, Chapter C.

b. MANNER OF SOUNDING.

Sounding with the Lucas lead was done under supervision of the expeditions' geologist, Dr. Ph. H. Kuenen, while the ship was lying still. The officer of the watch manoeuvred with the ship according to the position of the wire. The instruments at the end of the wire were affixed by the echo leadsman of the watch. After the sounding tube, the Sigsbee lead or the snapper had been affixed to the strayline, this was slacked away by hand. The sounding wire was then paid out a little until the point where the other instruments had to be affixed came within reach of the echo leadsman. After these instruments had been affixed the small spar was lowered until practically in the horizontal position, when the pointer of the measuring wheel was set according to the depth of the „lead" suspended under water. The wire drum could then be released and the wire let go. With the ship lying quite still, without pitching or rolling, the springs of the lever could be entirely released, veering being only braked by the friction of the instruments and wire in the water, by the slight friction of the two guide pulleys and the measuring wheel, and by the friction of the spindle of the wire drum in its bearings. When the ship was rolling the springs of the lever had to be kept under some tension to allow the lever to rise and fall. The rate of paying out was 3—2½ m/sec and the tension in the top end of the sounding wire 14—26 kilos. While paying out, the piece of wire visible above water was kept as near as possible vertical by manoeuvring with the ship. Towards the time that bottom was expected to be reached — the echo depth was meanwhile being taken by the echo leadsman of the watch and called out — the spring lever was set sharp. As soon as bottom was felt the wire drum was locked and winding-in was begun, as a rule, soon after. When a sounding tube is used reeling-in has to be begun very carefully, with the drum partly locked. In order to draw the sounding tube out of the ground rather considerable force is required, so that first of all any curves in the wire have to be drawn out, and the tension in the wire gradually increases until the sounding tube suddenly shoots out of the ground. The extra force required to withdraw the sounding tube from the sea-bottom was in many cases 50 kilos, and once even as much as 90 kilos. The tension at the top end of the line was then frequently more than 100 kilos, once 160 kilos (see table I, column 11). At the moment that the sounding tube came loose, or that the snapper or the Sigsbee lead was assumed to have been lifted, the reading of the dial was taken (table I, column 3) and the angle of slanting of the wire visible above water was recorded (table I, column 14). The rate of reeling-in, with fully loaded machine and wire of 1.0 mm, one sounding tube of 30 mm and two water bottles, averaged 2.5 m/sec. The tensions in the top end of the wire were then about as follows:

with	4000	metres	wire	paid	out:	80	kilos
,,	3000	,,	,,	,,	,,	76	,,
,,	2000	,,	,,	,,	,,	69	,,
,,	1000	,,	,,	,,	,,	66	,,

It was not until some 500 metres of wire still had to be reeled in that the tension began to decrease more quickly. While reeling-in it was not necessary to keep the line properly vertical; preferably the ship was manoeuvred in such a way that it drifted off a little from the wire, so as to keep the line well clear of the ship. Before the instruments were about to come above water the machine was stopped and the last length of wire carefully reeled in a little at a time. When this had proceeded so far that there was again as much wire paid out as what was started with before letting go, the reading of the dial was taken (as a rule this was not identical with the initial reading) and converted to the reading which it would have shown if reeling-in had been continued until the sounding tube had come above water. This converted reading of the dial of the measuring wheel was noted (table I, column 4) and in most cases was negative. The difference between the two readings indicates how much would have been reeled in according to the measuring wheel if reeling-in had been continued until the sounding tube showed above water (table I, column 5).

c. SOURCES OF ERRORS.

The figures given in table I, column 5, do not represent exactly the wire depth, and for this there are various causes:

1. The revolutions of the sheave of the measuring wheel were transmitted to the counter by a set of geared wheels. Consequently the figure indicated by the pointer varied to a constant amount with every revolution. The length of wire reeled in at one revolution depended on the diameter of the sheave and the thickness of the wire. The sheave groove gradually got worn down during use, and wires of different thickness were employed, so that the length of wire reeled in at one revolution did not, as a rule, correspond to the variation in the indication of the counter. If the radius of the groove in the sheave was originally R and sounding wire of a diameter 2r had been reckoned with, then the counter, if properly constructed, should indicate after one revolution $2\pi(R+r)$. When, however, the sheave groove is worn down to a readius R′ and a wire line 2r′ thick is used, then after one revolution the indicator gives $2\pi((R-R')+(r-r'))$ too much, thus, for a counter reading 1: $\frac{1\,(R-R'+r-r')}{R+r}$.

2. The depth, disregarding slanting of the wire and curvatures, is equal to the length of the wire just before the sounding tube is released or the snapper raised. When a sounding tube was used which had penetrated into the sea-floor, this moment was clearly to be seen on the tension meter. The line was then stretched by a tension which directly above the instruments amounted, for instance, to 90 kilos and at the sounding machine 110 kilos, thus giving a mean tension of 100 kilos. The tension at the measuring wheel when reeling in was not, as a rule, equal to the mean tension in the wire at the moment of pulling out of the ground, but in the case taken above averaged, say, 70 kilos, so that the measuring wheel did not record the elongation of the wire caused by the load being increased from 70 to 100 kilos.

3. In consequence of various currents in the water, both at the surface and at various depths, and also as a result of the ship's drift and faulty manoeuvring, the wire is not suspended vertically but is more or less at an angle and curved. When reeling in is begun, before the sounding tube is withdrawn from the bottom, the curves are only slightly drawn out; one need only imagine how much force is required to draw a wire transversely through the water and how slowly that takes place.

4. The average temperature of the sounding wire in the water was generally lower than that where the line passed over the measuring wheel. Consequently the length of wire measured was slightly on the high side.

5. The sounding wire was laid over the sheave of the measuring wheel in a groove which originally was V-shaped. Passing from the guide pulley fitted against the hull, the wire retained its

fixed position, but on passing from the measuring wheel to the drum it was drawn by the guiding rollers now to the left and then to the right, against the sides of the groove. Where the wire lies up against a side wall of the groove it is farther away from the spindle than when it lies in the bottom of the groove. The result is the same as when R' has become greater and the indication of the counter is consequently too low. The sheave rotates somewhat more slowly than the length of wire lying in the middle of the groove, and quicker than that lying up against a side wall. In other words, the wire in the centre of the groove slips somewhat over the sheave of the measuring wheel in the direction of rotation, whilst the wire lying up against the side of the groove slips counterwise to the direction of rotation. The extent of this slip is independent of the tension in the wire. (It is to be noted that this error does not occur with machines where the measuring wheel is free to adjust itself in the plane of the wire, as is the case, for instance, with our winding machines for serial observations).

6. There being a certain amount of friction in its ball bearings, the sheave of the measuring wheel will be somewhat behind the wire in its movement; the wire slips a little in the direction of rotation of the sheave and as a consequence the reading of the counter will be slightly too low. This slip increases inversely with the tension in the wire line; when reeling out it will therefore be greater than when reeling in. On the other hand there is the possibility that when being run out quickly and irregularly the line will jump for a moment from the sheave, and the sheave — in consequence of its inertia — will rotate under the wire quicker than the line runs out.

d. MAGNITUDE OF THE ERRORS. CORRECTIONS.

The corrections to be made for the errors resulting from the abovementioned causes — at least if such is deemed necessary and is possible — are named successively: 1) correction for measuring wheel and wire thickness, 2) correction for elongation, 3) correction for slanting, 4) temperature correction, and 5) and 6) apparent slip. The corrections for 5 and 6 have been combined because they cannot be determined separately, and have been mentioned last because their magnitude can only be seen from a comparison of the wire soundings with echo and thermometrical soundings.

1. Correction for measuring wheel and wire thickness.

The measuring wheel was constructed for a wire of 1.55 mm gauge. After 27 revolutions of the sheave the counter indicated 15 metres more. The exact diameter of the sheave ought, therefore, to have been $\frac{15000}{27\pi} - 1.55 = 175.2$ mm, but according to the construction drawing it was 175.0 mm. The sounding machine on arrival at Rotterdam was inspected by an officer who reported to me that everything was in order. I did not ask whether he had carefully checked the measurements of the sheave, and as he was soon after replaced by another officer there was no use in making enquiries afterwards. The diameter of the sheave was not checked — here I must confess to negligence on my part — until more than 100 km of stranded wire of 1.55 mm and a good 400 km of piano wire of 1.0 mm had been reeled out and in again over the measuring wheel. The groove in the sheave, which originally was V-shaped as shown in fig. 1 A, had by then been worn down to a W shape as shown in fig. 1 B. Supposing that the diameter of the sheave at the time of delivery was 175.0 mm, then when using 1.55 mm wire the counter registered per 1000 metres wire 1.7 m too much, and when using 1.0 mm wire 4.0 m per 1000 m too much. At the first check the diameter in the centre was found to be 173.0 mm and the corrections were then —13 and —16 per thousand respectively. After another 250 km piano wire of 1.0 mm had been paid out and reeled in again over the measuring wheel the shape and diameter of the sheave, and

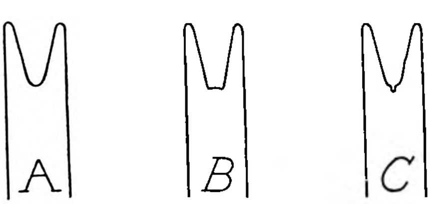

Fig. 1.

thus also the corrections, were found to have remained practically the same. The fact that the groove in the sheave had become worn to a W shape is clearly due to the slip brought about by the wire being drawn sideways. Apparently the wear with piano wire is practically nil. Fig. 1 C shows a section of the fixed guide pulley. The wear of the groove, at least for the greater part, was due to the pulley having once run hot and the sounding wire (1.0 mm.) then running over the stationary sheave.

In determining the corrections for measuring wheel and wire thickness it was assumed that the sheave diameter agreed originally with the construction drawing and that the wear is to be ascribed solely tot the use of stranded wire. These corrections are given in table 1, column 7.

2. Correction for elongation.

The elasticity coefficient of hardened drawn steel is given as 1 : 2.200.000, that is to say, a rod of that metal 1 metre long and with a sectional area of 1 cm² under a load of 1 kilo stretches $\frac{1}{2.200.000}$ metre. The elongation is taken to be inversely proportional to the section and proportional to the length and load. Piano wire of 1.0 mm diameter has a sectional area of 0.008 cm². A thousand metres of that wire under a load of 1 kilo would therefore stretch $1000 \times \frac{1}{0.008} \times \frac{1}{2.200.000} =$ 0.05 m. From tests taken on board with piano wire of 1.0 mm an elongation was found of 0.04 m and with stranded cables of 1.55 mm and 4.0 mm respectively 0.08 and 0.04 m. The values found by these tests were used for calculating the errors for elongation.

Although the elongation corrections are not large, I nevertheless applied them to the wire soundings, because it could not be foreseen whether it was admissible to ignore them when making comparisons with echo and thermometrical soundings; they are given in table 1, column 12. The average corrections for difference in elongation when running out and reeling in piano wire of 1.0 mm amounted to 0 for 1000 m and + 2 m for depths of 2000—5000 m. For the stranded wire of 1.55 mm these values are double. Once, when the limit of breaking strength of the 1.0 mm wire was dangerously near being reached when pulling the sounding tube out of the ground, the correction for elongation was + 14 m.

3. Correction for slanting.

Prior to the invention of the echo depth sounder and the use of counter-pressure-protected and nonprotected thermometers of great accuracy side by side, which afford the possibility of measuring the depth in various ways simultaneously, it was not possible to get a well-founded idea of the magnitude of the error caused by curvature and slanting of the wire. Tydeman [1]) assumed this error, as a rule, to be small, apart form exceptional cases such as in Strait Lifamatola. Schott wrote that he considers it hardly possible that the depth would ever be measured too large with the wire lead, even in very strong currents, but later on [2]) he is not so optimistic in this regard. Siedenburg [3]), on the other hand, speaks of the great influence of strong submarine currents (he used, it is true, hemp lead line), and Drygalsky [4]) is of opinion that this error may amount to 100 metres and more.

Considering my former experience, chiefly in the East Indian Archipelago, I was inclined towards the opinions of Siedenburg and Drygalsky, in which I was soon strengthened by the experience gained on the outward voyage and in the beginning of the expedition's work.

When sounding on the outward voyage in the equatorial current of the Indian Ocean, the wire was kept well vertical while reeling out by steaming up against the current. While reeling in, the wire inclined 15° ahead, under the influence of the greater tension. Apparently the surface current layer was so thick, whereas the current changed towards the bottom in force and direction,

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1) Siboga Expedition, Description of the ship and appliances used for scientific exploration, page 24.

2) Ann. der Hydr. 1923.

3) Report by Commander A. F. Siedenburg, Royal Dutch Navy, in command of H. M. S. „Cachelot", 1858—1859.

4) „Deutsche Südpolar Expedition", vol. VII.

that steaming against it with the visible part of the wire kept vertical, did not neutralise the total effect. The wire must have made a wide curve, so that the length of wire run out must have been much more than the depth. And indeed the echo sounder indicated a good 100 metres less than the length of wire; the depths at that spot were 4600—4700 metres.

When sounding in the Makassar strait, where there was again a strong current (about 2') and good sight of land, it was endeavoured to keep the ship at the same spot by holding to a landmark abeam, and the line then inclined at a considerable angle astern, so that the length of wire run out must again have been much more than the depth. After bottom had been touched the ship was allowed to drift and the line was gradually reeled in, leaving the lead on the bottom until the least length of line was reached; and yet the line gave 100 m too much, at a depth of 2000 metres.

The influence of the various currents on the wire was found to be still greater when taking water samples in the Sarangani and Palmas straits. Notwithstanding the vertical position of the visible part of the line, the samples were taken from far too shallow depths; there must have been such a curve in the wire that the waterbottles tipped at the wrong levels. The uppermost layer was 300 m thick, and the surface current was 2—3 knots or more.

At the time that the abovementioned observations were made, the surface current was in every case strong, but the fact that even without that a large error in depth can be made was quite apparent from a sounding taken south of Boeroe, where the surface current was nil and the ship was kept in position, and yet after the lead had passed the 500 m, the line showed suddenly an inclination of 15°. The current below that level must, therfore, have been very strong indeed.

Farther on, the great effect of submarine currents on curves in the line will be demonstrated bij comparisons with echo and thermometrical soundings. It will be seen that where there is no surface current and the visible part of the line is kept vertical, the effect of the curvature under water is nevertheless 20 metres on the average, and that with a surface current of some strength and notwithstanding the visible part of the line being kept vertical, the curvature on the average is even almost 50 metres. These corrections are for soundings of more than a few hundred metres, independent of the depth.

A remark made by Wüst [1]), that the occurrence of strong submarine currents in a direction different from that of the surface current, as met with in various coastal areas and in equatorial currents, is of particular influence, points in the same direction.

4. Temperature correction.

The coefficient of expansion of steel is 0.00001239, so that with a temperature change of 30° the length of 1000 m piano wire changes only 0.4 m. It is not known what the temperature of the wire was at the measuring wheel when reeling in, but anyhow it was cold to the touch. In any case the correction for differences in temperature of the wire were so small as to be negligible.

5 and 6. Apparent slip.

The correction for the two errors combined under the name „apparent slip" will later on be seen to be very large, presumably about —1 %. An idea of the magnitude of the *true slip* (6) may be obtained from the following:

When the lead, at the moment running out was begun, was 30 m below the surface, the counter was set at 30. On the lead, when reeling in, again reaching that depth of 30 m, the counter will register, not 30, but say 20. In that case the sheave of the measuring wheel, when reeling in, has described a distance of 10 m more than when running the line out, due to the difference in slip, difference in elongation and difference in temperature when running out and when reeling in. The line at the measuring wheel, while paying out, was under an average tension of 20 kilos, and while reeling in it was under an average tension of 70 kilos. For every 1000 m depth the difference in elongation for piano wire of 1.0 mm must therefore be $50 \times 0{,}04$ m $=$ 2 metres. Where the depth

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[1]) „Wissenschaftliche Ergebnisse der Deutschen Atlantischen Expedition", vol. IV, part I, page 142 — see also p. 155.

was 3000 m 6 of the 10 metres are to be ascribed to difference in elongation, —1 m to difference in temperature and the other 5 m to difference in slip. In that case, therefore, the wire has apparently slipped 5 metres more while running out than while reeling in.

These differences in slip were determined for 230 soundings with piano wire of 1.0 mm to depths of 6000 m, excluding soundings which gave abnormal slip differences. Taken on the whole it was found that the slip when running out was more than that when reeling in:

for 500	m.	depth	— 0.2 m
1500	„	„	+ 1.1 „
2500	„	„	+ 2.9 „
3500	„	„	+ 4.9 „
4500	„	„	+ 6.6 „
5500	„	„	+ 7.7 „

thus about 1 per thousand, but increasing relatively with the depth.

Some soundings, however, not included in the 230 mentioned above, showed much greater differences in slip, viz.

depth 1059	m	22	m more slip when running out than when reeling in
1335	„	25	„ „ „ „ „ „ „ „ „
3435	„	27	„ „ „ „ „ „ „ „ „
5700	„	194	„ „ „ „ „ „ „ „ „
9295	„	24	„ „ „ „ „ „ „ „ „
5380	„	53	„ less „ „ „ „ „ „ „

These, however, are exceptions. In most cases the slip difference was less than 7 metres.

If the slip may be taken to be inversely proportional to the average tension under which the wire passes over the pulley, then the mean true slip when reeling in would be ½ per thousand.

C. ECHO SOUNDINGS.

a. APPARATUS.

A description of the apparatus is to be found, i.a., in the ,,Hydrographic Review". Some particulars are given also in Volume I, Chapter C.

Nothing was to be detected of a directed radiation when using both Atlas A transmitters, though the distance between the middles of the transmitters was 105 cm.

b. MANNER OF SOUNDING.

1. With the Atlas apparatus set for ,,shallow".

The period of rotation of the neon lamp was regulated by means of a frequency meter. The dial was graduated in metres up to 200. The period of the neon lamp, with frequency meter acting, was about $\frac{2 \times 200}{1490}$ sec. The neon lamp lighted up when the echo struck the receiver. The point on the dial where the light from the neon lamp showed up depended from the echo time, but the figure read off was the echo distance (in metres) for the case that the average velocity of sound in the water was 1490 m/sec. The correction for the distance under water of the transmitter and receiver and the correction that had to be made on account of the positions of transmitter and receiver not coinciding, were allowed for in the scale.

The difficulty lies in eliminating secondary flashes. It is also to be borne in mind that powerful echoes also cause the neon lamp to light up if the echo distance is greater than 200 metres. If, for instance, the flash of light indicates 24, then the echo distance may be either 24 or 224.

2. With the Atlas apparatus set for ,,deep".

Observations with this apparatus were based on the ear and eye method. An illuminated pointer moved along the edge of a dial graduated in 5 m from 0 to 1200. The transmitter was powered at the moment the pointer passed the mark corresponding to the depth at which transmitter and receiver were situated. The period of rotation of the pointer, with the frequency meter of the recording motor acting was $\frac{2 \times 1200}{1490}$ sec, so that the number recorded by the pointer at the moment the echo was received was the echo distance for the case that the average velocity of sound in the water was 1490 m/sec.

The sound wave could be transmitted with the small D transmitter or with one of the A transmitters, or with both A transmitters. The shortest echo signal gave the D transmitter, and the impression was that the signal from both A transmitters together was longer than that from one of the A transmitters alone.

For the reception a choice could be made from 6 Atlas receivers, and sometimes also the Hughes deep-sea receiver was used.

After the apparatus had been in use three months the echo leadsmen had become perfectly skilled with it.

Remark: Although with the Atlas sounder the echo *time* is observed, a *distance* is read off,

this being the so-called approximated echo distance, i.e. the echo distance to be deduced from the echo time observed if the average velocity of sound in the water is 1490 m/sec. The echo time will in most cases be given in the same way, thus an echo time of 2 seconds being given as 1490 metres.

3. With the Hughes apparatus. Bij adjusting the voltage the time taken for the pointer to travel round the dial was set at 11¼ secs. It took some time to do this, but once the period was properly adjusted it was not subject to much change. The dial was graduated in hundredths of a second from 0 to 11¼ seconds, whilst a nonius enabled readings to be taken to a thousandth part of a second. The echo time was first approximately determined bij switching the receiver in such a way that the reception could be continually heard. The receiver was next switched so that the echo could only be heard when the nonius was placed at the exact point of the dial corresponding to the echo time. This observation left a little play.

The difficulties encountered when sounding with this instrument have already been dealt with in volume I, Chapter C.

Lieut. Veldman, the chief echo leadsman, and one reserve echo leadsman were specially trained in sounding with this apparatus.

c. SOURCES OF ERROR IN RECORDING THE ECHO TIME.

I. When recording with the Atlas sounder.

1. When in consequence of rough sea the water pressure on the membranes and the hull plates changes for a moment, the membranes and the hull plates between the frames will change somewhat in shape, as a result of which the elasticity of the membranes and plates and thus also the own frequency of oscillations of transmitters and receivers are slightly altered. The receivers, on being struck by the echo, will not immediately oscillate with the full frequency of 1050. The oscillations will be irregular at first and only after a while will the resonance of the receiver fully answer to the echo. With the first irregular and weak oscillations the recording instrument will not come into action (echo not audible or only indistinct), so that the indication is slightly retarded and the depth recorded will be too large. This phenomenon is called the *breathing of the receivers.*

2. In order to reduce the indicated approximate echo distance to the true echo distance, first a conversion has to be made to echo time. This conversion was done graphically. Verification in Holland of the period of the recording motor showed it to be 1.611 sec, i.e. corresponding to the fictive velocity of sound of 1490 m/sec. Off Cape Guardafui, just after having passed from a moderate to a tropical climate, the period with frequency meter in the middle was found to have diminished to 1.564 sec. Subsequent changes were less important. As a consequence the conversion graph had to be altered 4 times; it could not very well be altered every time that a change in the period was observed. During the second half of the expedition the period remained fairly constant at 1.560 sec. Owing to the *conversion graph not having been modified for every variation* in the period of the recording motor, errors have crept in.

3. It takes some time for the echo leadsman who works with the Atlas deep sounder to react to the impression of his hearing the echo. When he thinks he hears the echo, some time has in fact already passed since the sound reached his ear, so that the echo time as observed by him is too long. The *mean* error of an echo leadsman resulting from this delay in reaction has been termed the *personal error.*

On board the Snellius an attempt was made to minimize this error by fitting around the depth scale a rotatable ring in which a narrow radial slot was cut. In this way the illuminated pointer was only to be seen during the moment that it passed behind the slot. The idea was to make the moment at which the flash was seen through the slot coincide with the moment the echo was heard, by setting the ring in the position required to make the two momentary impressions exactly coincide. This device, however, gave very little improvement, if any; apparently we lack the power to determine precisely the coincidence of an optical and an audible signal.

4. Even when the frequency meter remains properly adjusted while sounding, the number of revolutions is not absolutely constant. Moreover, while sounding it may quite well

have occurred that the necessary attention was not paid to the proper adjustment of the recording motor.

5. The echo leadsman working with the Atlas sounder set for „deep" *estimates* the point where the illuminated pointer is at the moment he thinks he hears the echo. The error resulting from the inaccuracy of the estimate, together with the error sub 4, gives the *error of observation,* which depends for a great deal on the attentiveness and skill of the leadsman.

II. *When recording with the Hughes sounder.*

An error may arise from the *period* not being properly adjusted or changing while sounding. Further, it is possible that there is a *little play* in the position of the nonius at which the echo is heard. Finally, after frequent use there will be *wear* of the ebonite due to sparking, this affecting transmission at the right moment.

d. MAGNITUDE OF THE ERRORS IN RECORDING THE ECHO TIME. CORRECTIONS.

I. *When recording with the Atlas sounder.*

Re 1. *The breathing of the receivers* was seldom noticeable. No correction can be made for it. The inaccuracy which still remains on this account is at most 2—3 metres and therefore only of importance for shallow soundings.

Re 2. Judging from the periods used and the results of the check measurements, 50 % of the conversions, owing to the *conversion graph not having been modified for every variation,* will be subject to an error smaller than 0.51 %; the probable errors in observation resulting from a slightly incorrect conversion graph may thus be taken to be as follows:

for depths of	500,	1250,	2500	and	4300 metres,
respectively	3	6	13	and	22 metres.

Re 3. An idea of the magnitude of the *personal errors* to be expected is given by tests taken by the Signal-Gesellschaft at Kiel, from which it appeared that the reactions varied in time for different persons and gave an average error of 37 metres. The personal errors of our own echo leadsman could not be determined until we had at our disposal the largest possible number of comparisons with wire and thermometrical soundings, thus not until after the end of the expedition. From the first sounding tests made on the outward voyage and in the beginning of the expedition the personal errors of the echo leadsmen appeared to differ by some tens of metres. The drawing of fair sheets could not be put off until the personal errors had been determined, but the soundings could not very well be left uncorrected, because not only were the soundings too large as a result of the reaction times but also these reaction times for the various leadsmen differed so much that when a leadsman was relieved false depth jumps occurred. This difficulty was met by approximating the differences in reaction times as soon as possible and reducing the soundings of the various leadsmen to the same mean level. For this approximation two series of tests were made.

In the first place a series of measurements were taken with the ship lying-to over a flat horizontal sea-floor, so that the echo time varied little and only gradually. In each series of measurements the echo time was observed by at least 6 echo leadsmen in rapid succession. The average of these 6 or more soundings was determined and also the amount by which each sounding differed from that average. These differences I termed the *variable errors.* The average of these variable errors of one and the same leadsman was determined for each test and called the *personal deviation* of the leadsman for that test.

As these tests, with very little variation, if any, in the echo time, presumably gave too favourable a picture, another test was made under circumstances which were unfavourable compared with what usually prevailed. Off Ternate sounding runs were made in a mark line on the small volcano Maitara. The sea-floor there is rugged and the depth varies between 500 and 300 metres, diminishing in some places and increasing in others. At the first run the angle at which the mountain top was seen above the beach was measured every minute and thereby the position of the ship on the mark

line determined minute for minute. When the next runs were made it was noted every time at what moment the angles observed on the first run were again obtained. In this way the position of the ship at every moment of each run could be accurately determined with reference to the position fixed on the first run. Soundings were taken by 6 leadsmen, each of which made four runs, one with the A_1 transmitter up the slope, one with the same transmitter down the slope, one with both A transmitters up the slope and one with the Hughes sounder down the slope. From the 6 runs of the 6 leadsmen with the A_1 transmitter up the slope six curves were plotted by setting out the ship's position along the X axis and the echo distance there recorded along the Y axis; scale 1 : 10.000. The same was done with the 6 runs made by the 6 leadsmen with the A_1 transmitter down-slope, and so on. In this way 4 rods were obtained each consisting of 6 curves, and from each rod the curve of the most probable echo distance was determined.

From these various tests it was found that the personal deviations varied with the physical and psychical condition of the observer and also, to a certain degree, with the sharpness of the echo, but for the same leadsman in the same test they were practically constant, whilst the variation taken over the various tests was not so great or it would be worth while to correct our soundings for the average personal deviations. Further it appeared that the personal deviations were the same when using either one or both of the A transmitters.

From the 586 soundings off Maitara and 75 series spread over 6 tests, the *mean personal deviations* of the echo leadsmen regularly sounding were estimated at 0, —5, —10, —20 and 0 metres respectively, and all further soundings were corrected accordingly.

The sounding tests described above were continued until finally we had at our disposal comparative data obtained from 1609 soundings. The tests were carried out at all possible depths from 300 to 10,000 metres, whilst 677 soundings were taken under adverse conditions, so that it may be assumed that the picture given by these tests corresponds to that of the aggregate soundings of the expedition.

From these tests 79 personal deviations were determined for 9 leadsmen; the rectified mean personal deviations of the leadsmen regularly sounding were: 0, —10, —9, —10 and —8. If the different single personal deviations of the regular leadsmen as found by these tests are reduced by the mean personal deviations applied, then the differences give an idea of the *inaccuracy of the corrections*. This inaccuracy is expressed by a probable error of 11.9 m.

Re 4 and 5. An idea of the inaccuracy caused by the *error in observation* is obtained by deducting the different single personal deviations as found at the tests from the variable errors with which these personal deviations were determined (1412). This inaccuracy is indicated by a probable error of 11.3 m.

The *conclusion* from the foregoing is that *the echo times recorded with the Atlas sounder set for „deep" are on the average too high by an amount as yet unknown, which corresponds approximately to the mean of the reaction times of the Snellius echo leadsmen. Moreover these echo times are subject to a variable amount of error giving an inaccuracy which may be expressed as follows:*

echo time: 500, 1250, 2500, 4300 m.
probable error: 17, 18, 21, 27 m.

The echo times determined with the Atlas sounder set for „shallow" may, provided the instrument is in order, be at most 2—3 m out, mainly due to the breathing of the receivers.

II. *When recording with the Hughes sounder.*

From what has been said under c II it follows that it is improbable that there are large errors in the echo times recorded with the Hughes sounder. This instrument having been but little used, there will not be any wear worth mentioning.

In order to ascertain the value of the Hughes soundings, in addition to those off Maitara two other tests were made, one near Makian-Moti and further soundings near the Toekangbesi; the latter, however, yielded no results owing to the extreme unevenness of the seabottom.

The test near Makian-Moti was taken over a fairly flat bottom at a depth of about 500 m. In three hours 21 wire soundings were taken with the large Lucas apparatus and a weighted Kelvite sinker, while the ship was drifting. At the same time 130 soundings were taken wit the Atlas D transmitter, 92 with an Atlas A transmitter and 85 with the Hughes sounder. There was a fairly strong

current running and during half an hour a strong wind blowing from the same direction, in consequence of which the ship drifted off about 3000 m in spite of manoeuvring on the wire. Presumably as a result of this the wire soundings are inaccurate and on the average much too high.

The test at Maitara showed that on an average the Hughes soundings were 16 m less than the average of the Atlas soundings, and that the personal deviations were +7(17), —3(17), +4(9), +11(6), +10(9) and —7(8). Jugding from the test near Makian-Moti it seems probable that the

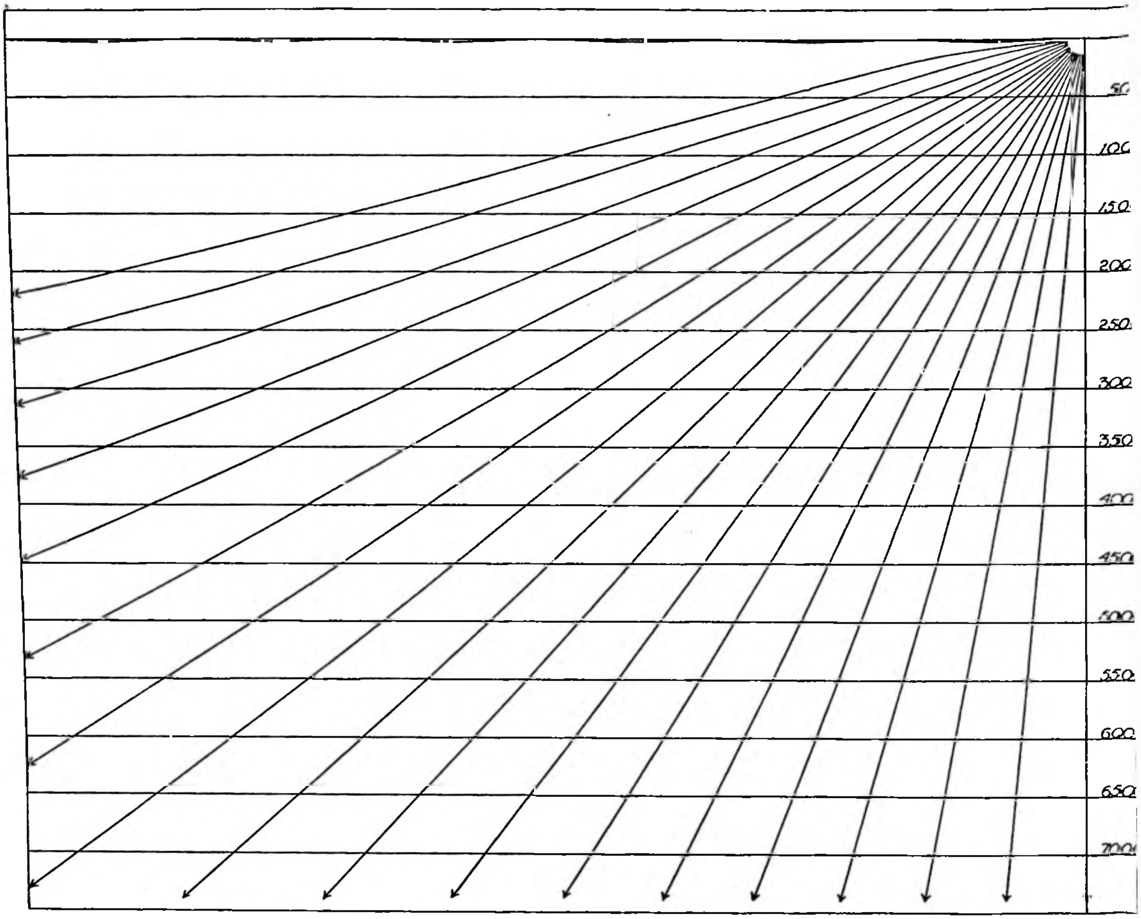

Fig. 2. Diffraction, Eastern half of Indian, Archipelago.

Hughes soundings there gave on an average 20 m less depth than the Atlas A soundings and 10 m less than the Atlas D soundings, whilst the personal deviations were 0(10), 0(11) and 0(11).

Fifty per cent of the variable errors in these tests are between —9 and +12 metres.

e. CONVERSION FROM ECHO TIME TO ECHO DISTANCE.

It was assumed that in water sound propagated in a straight line, which is not quite correct. Owing to the fact that it passes through water varying in physical properties, thus at varying velocity, there is a break when the sound wave does not strike the separatory planes perpendicularly. In fig. 2

the mean curvature in the Indian Archipelago is given for the case that the separatory planes are flat and horizontal. This figure shows the reflexion given to the almost horizontally transmitted sound waves at about 25 m depth, the wide deflection of the waves transmitted at very large angles to the vertical and the very small deflection of the almost vertically transmitted waves. Considering that the sea-floor slope is seldom more than 20° and, therefore, the echo received seldom travels along a path deviating more than 20° from the vertical, the deflection when sounding will not usually be of much importance, provided the various layers of water are separated from each other by flat planes. In this respect we have to do with an unknown factor. Where various layers of water flow over each other the separatory planes will be undulated, but it is not known how great the influence of this may be on the direction of propagation of the sound.

The curvature resulting from the different current velocities and directions of flow at different depths and the curvature resulting from the earth's rotation can only be a few minutes and need not be considered here. Finally the direction of propagation will change again where the sound passes along the absorbing ship, but this has no effect worth mentioning on the echo distance.

The *velocities of sound* were calculated with reference to the temperatures and salinities determined for a nearby station and with the aid of the „Tables of the velocity of sound in pure water and sea water for use in echo-sounding and sound-ranging" published by the British Admiralty. The horizontal velocities (V'^{s}_{h}) were calculated for every 200 m, and the mean vertical velocities (V'^{s}_{m}) were obtained from harmonic averages of V'^{s}_{h}. The echo distances given in table I (appendix 2) have, moreover, been corrected by recalculating table 4 in the abovementioned book with the corrected values for μ and p. The corrected tables 4 for the eastern half of the Indian Archipelago and for the Sulu sea are given in appendix 1, as also the velocities V'^{s}_{h} and V'^{s}_{m} which were used for calculating the echo distances in table I. It is seen that the values for various parts of the archipelago and in the various monsoons differ but little.

The British Admiralty tables are based on theoretical formulae and laboratory experiments, and it is not known in how far they are accurate; in my opinion not much value is to be ascribed to check measurements in horizontal direction, seeing that in such tests the break, reflexion and interference have too disturbing an influence.

If the bottom dips there is an error, because in the conversion the value V_m is used which applies to a greater depth than that of the plane which reflects the sound to the receiver. The error resulting from this, however, is very small; in the exceptional case of a dip of 20° at 7000 m depth the error of V_m is 3 m/sec, resulting in an error of 14 m in the echo distance.

f. INFLUENCE OF BOTTOM SLOPE.

If the slope of the bottom plane reflecting the sound signal to the receiver is $\alpha°$, and the echo distance a, then the depth of the reflecting bottom plane is a cos α and the depth figure a cos α should be at a point situated at a distance a sin α from the depth figure given when no correction is made for the sea-floor slope.

Sections were drawn of almost all the cross sounding lines. By measuring the slope of the section at regular distances, the following frequency table of the bottom slope is obtained, assuming that the sections are perpendicular to the depth lines:

slope in °: .	0	1	2	3	4	5	6	7	8	9	10
frequency: .	1865	2168	1336	847	523	475	261	227	175	120	117
slope in °: .	11	12	13	14	15	16	17	18	19	20	21
frequency: .	83	75	47	39	44	26	25	19	13	24	10
slope in °: .	22	23	24	25	26	27	28	29	30	31	32
frequency: .	9	8	7	5	6	4	4	2	1	3	4
slope in °: .	33	34	35	36	37	38	39	40	41	42	43
frequency: .	3	0	2	0	1	0	1	1	0	0	0
slope in °: .	44	45	46	47	48	49	50	51	52		
frequency: .	0	0	0	0	0	0	0	0	1		

The bottom slope was measured at 8581 places. 50 % of the slopes are less than $1\frac{1}{2}^0$, 85 % less than 6^0 and 1 % are slopes of 20^0 or more. With a slope of $1\frac{1}{2}^0$ $1-\cos\alpha = 0.3\,^0/_{00}$, $\sin\alpha = 26\,^0/_{00}$; with a slope of 6^0 $1-\cos\alpha = 5\,^0/_{00}$, $\sin\alpha = 104^0/_{00}$, and with a slope of 20^0 $1-\cos\alpha = 60^0/_{00}$, $\sin\alpha = 342\,^0/_{00}$.

Although a steep bottom slope may make the depth differ considerably from the echo distance, there were very few cases where a large error resulted from not making a correction for the slope. Moreover, it is to be borne in mind that steep slopes naturally can extend over only short distances and that in most cases they are accompanied by broken bottom or terraces, so that the influence of not correcting for bottom slope is of more effect for the shape of the sea-floor than for the deep-sea chart.

The terraced form of sea-floor was noticed for the first time in the Red sea. Near Jebel Teir some soundinglines were laid East-West. Soundings were taken with the Atlas sounder at distances of only 6 metres. It then occurred that for a time the depth remained constant, say 300 m, until one signal gave no echo, this being followed by a large number of soundings giving a depth of 200 metres more. Apparently over a distance of at most 12 m the depth had suddenly increased by 200 m.

The same phenomenon was frequently met with in the Indian Archipelago, but there terraces were also often sounded in another way. The first instance of this was off Manado Toea.

Manado Toea is a small volcano of the shape of a truncated cone, at least as regards the part above water. The soundings were taken in the expectation that under water the slope would be of the same regularity as above water, the object of the test being to ascertain whether it made any difference whether the echo was received from forward or from aft. The test was carried out in a similar manner to that described near Maitara, but here only the chief echo leadsman took the soundings. For the first run, up the slope, the A_1 transmitter was used (A_1 in), for the second the same transmitter in opposite direction (A_1 out), whilst for the third run, up the slope, both A transmitters were used ($A_{1,2}$ in). The depths varied from 1400 to 300 m.

These soundings brought surprises. From the observations made it was at once apparent that on steaming down the slope there was something exceptional. The 61 soundings of the (A_1 in) run were on the whole clear; only one sounding was noted as „bad" and 4 as „broad".

The 57 soundings of the ($A_{1,2}$ in) run were too hard at shallow depth, the telephone being very noisy. For depths over 600 m, however, the soundings were clear; two were noted as „broad".

On the (A_1 out) run, on the other hand, only 42 soundings could be taken, of which 3 were „bad", 1 „soft" and 15 „broad", whilst once no echo at all was heard. Apparently, on steaming down the slope the echoes did not come through so clearly.

On the sea-floor section being constructed (see Plate I) the soundings of (A_1 in) and ($A_{1,2}$ in) were found to agree exactly and, further, successive soundings gave echo distance circles intersecting each other at one point (see the black lines). Consequently in successive soundings one and the same point of the bottom must have been sounded. The successive arcs which intersected each other at one point definitely marked out a limit within which projecting points of the section, or projecting edges of the mountain, must lie. The whole section was thereby approximately established.

On plotting the echo distances of the (A_1 out) run (the red lines) the circles were found to cut off large pieces of the projecting points already determined. Part of these echo distance circles, however, touched the lines which could be drawn horizontally from the projecting points. Most probably, therefore, under water Manado Toea is terraced, and while steaming towards the mountain the projecting edges were sounded, and while steaming away from it not the nearest edges aft but the more distant horizontal surfaces of the plateaux underneath the ship were sounded.

From this it follows that when one sound signal gives two echoes and those echo times do not differ much, the echo leadsman is only able to observe the clearer of the two, and that the intensity of echoes from astern is less than that of echoes from forward.

This latter fact is to be accounted for by the absorption of the ship. With the transmitters situated forward the radiation in forward direction is not interrupted, whereas the radiation aft (and also, to a certain extent, to starboard) is partly absorbed by the ship. With the receivers in the flat ship's bottom a little forward of midships, the echoes coming from aft are slightly more absorbed

than those from forward. The echoes coming from aft will also be impeded more than those from forward by the bow water which passes under the ship and in which there are air bubbles. It is also possible that the air bubbles of the screw water deflect the echoes from astern towards the ship, in consequence of which the intensity of the sound reaching the receivers is reduced.

Where the sea-bottom is uneven it may also occur that the echo distance is greater than the depth. A remarkable instance of this was given by the soundings of station 189 in the Gulf of Boni. Simultaneously with the first wire sounding, which gave 1866 m, the Atlas sounder gave 1913 m. The difference between the two soundings is not great, particularly when the average corrections arrived at farther on are applied. With the heavy sounding tube a depth of 1751 m was then recorded, while the Atlas lead gave 1984 m; this Atlas sounding was checked by several echo leadsmen. The difference between wire and Atlas depths in this case was too large to be attributed to inaccuracy in the observations. Shortly afterwards the Atlas lead again gave less depth. During the last wire sounding the ship had drifted a little. Consequently at that spot the sea-floor must have been somewhat of the form indicated in fig. 3. A remarkable fact was that the sounding tubes brought up soft mud here.

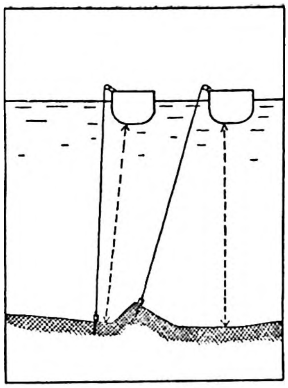

Fig. 3.

D. SIMULTANEOUS DEPTH SOUNDING WITH WIRE, THERMOMETERS AND ECHO. ACCURACY OF THE SOUNDINGS.

Before and during the expedition 347 soundings were taken simultaneously with the wire and Atlas sounder, and of these 149 were taken at the same time with thermometers. Further there were 98 soundings made simultaneously with the Hughes and the Atlas instruments for comparison, and in the case of 11 of these the wire depth was also determined. These comparisons are given in appendix 2, tables I and VIII.

The signification of various columns in table I and also the corrections and conversions have already been dealt with for the greater part in the foregoing pages. In column 15 the current is given in nautical miles per hour where that was known or could be estimated. If there was a current at the surface, but the strength could not be estimated, this is indicated by "cur" (current). In column 16 "slope" does not necessarily signify that the sounding was actually taken over a slope in the sea-floor, but denotes the possibility that such was the case. "Rugged" and "steep" indicate that there is a greater possibility that the floor was uneven or that the sounding was taken over a steep slope. "Flat" denotes that it is practically precluded that the sounding was taken over an uneven or sloping sea-floor.

The water pressures at the place where the thermometers were inverted and the inversion depths deduced therefrom were obtained from the leader of the expedition. With thermometer depths less than 800 m there is a chance of an inaccuracy due to insufficient time for adaptation. The readings of the various kinds of unprotected thermometers were determined at 100 and 200 kilos, at 300, 400 and 600 kilos and at 500 kilos pressure. This verification was done by the Physikalisch-Technische Reichsanstalt at Charlottenburg.

Where in the last column "good opportunity" is reported, this means that *while sounding* it appeared that the wire on being paid out and the sounding tube drawn out remained vertical, that there was no current running, no abnormal slip was noticed, the echo was clear and it is not probable that the floor sloped.

Finally it is to be remarked that changes in the instruments are most apt to have taken place while the ship was in dock and under repair, that is to say between the stations 24a and 25, 170 and 172, and between 309_1 and 320. During the last docking the big Atlas transmitters were replaced by new ones.

Notwithstanding the large number of soundings taken simultaneously in two or more different ways, it is not easy to draw definitive conclusions from the comparisons, such being due to the numerous factors affecting the accuracy of the soundings. These factors, as far as the echo soundings and wire soundings are concerned, have already been indicated. The sources of errors in thermometrical depth soundings have been set forth by *Wüst* in "Oceanographische Methoden und Instrumente" of the Meteor work. The accuracy of our thermometrical depth soundings will be dealt with in the oceanographic part with reference to the extensive data furnished by the serial observations; as far as the thermometrical soundings with the Lucas lead in particular are concerned, it is remarked that in view of the distance that the thermometers had to be hauled up to be inverted, and considering the length of the stray-line, the inversion, if working properly, may have taken place anywhere between 3 and 36 m from the bottom.

The effect of apparent slip, the effect of the currents on the sounding wire and in how far the

inclination of the visible length of wire may be a reliable criterion for a correction, further the average reaction time of the echo leadsmen and the influence of a sloping and uneven sea-floor, are all still unknown factors. If the magnitude of the errors possibly arising therefrom are to be determined and reliable corrections arrived at, the observations must be divided into those where these various factors have played a role and those where they have not.

In the first place a comparison will be made of: the wire soundings taken with no (or only little) surface current, when the slanting of the wire while sounding was practically nil and the reading of the measuring wheel after reeling in was normal; the echo soundings taken over presumably flat horizontal bottom; the thermometrical soundings showing no particularly large deviations from the soundings taken with some other instrument.

In tables II, III and IV a summary is given of the soundings which answer the above requirements. Table II shows the difference of wire depth minus Atlas depth, Table III thermometrical depth minus Atlas depth, and Table IV wire depth minus thermometrical depth. The differences are arranged according to depth. The number of comparisons for each table is not large, and is too small to calculate the average differences for a certain depth. For this reason the tables have been plotted on millimetre paper so as to arrive at the average differences graphically. The corresponding lines indicating the average differences are only moderately accurate, particularly for the great depths.

An approximate idea of their accuracy is obtained by grouping the graphical representations concentrated around the depths 1250, 2500 and 4300 metres (groups 1, 2 and 3), measuring off the amounts which the various points giving the measured differences lie above and below the corresponding lines, and then determining for each group the value $\frac{2}{3}\sqrt{\frac{\Sigma v^2}{n(n-1)}}$. For the approximate probable errors in these groups we then get:

	Group 1.	Group 2.	Group 3.
Table II	5.5	7.1	6.6
„ III	5.7	4.7	6.3
„ IV	3.0	3.1	1.9

If the stations used for one of the tables II, III or IV were all to occur also in the other two tables, then II—III = (W—A) — (T—A) = (W—T) should agree exactly with the differences (W—T) indicated by table IV, or II—III—IV should be 0. This should also be the case if, in proportion to the accuracy of the surveys, a very large number of comparisons were available. As neither is actually the case, it is to be expected that the average differences (W—T) deduced from tables II and III will not tally with the average differences given by table IV.

In fact one finds for II—III—IV remainders as indicated below:

Depth	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500
II	—1	—7	—9	—10	—11	—12	—12	—13	—13	—14	—15
III		—36	—41	—44	—47	—47	—47	—46	—45	—44	—42
II—III		+29	+32	+34	+36	+35	+35	+33	+32	+30	+27
IV		+15	+15	+15	+14	+11	+8	+4	0	—4	
II—III—IV		+14	+17	+19	+22	+24	+27	+29	+32	+34	

The remainders are certainly very large, although they fall within the limits allowed by the approximate probable errors. As a matter of fact one finds for the probable error of the remainders $\sqrt{5.5^2 + 5.7^2 + 3.0^2}$ etc., giving for

group 1	group 2	group 3
7.4	8.6	9.1

And yet the uniform increase of the remainders with the depth gives an inducement to investigate whether the remainders are not for the greater part due to constant errors having been made over a certain period which were not made during another period. Since the thermometrical soundings were only taken from station 130 onwards, it is obvious to suppose that during a period prior to 8.XI.29 errors were made of a constant character which were not made after that date. And thus we arrive at the question whether the diameter of the measuring wheel at the beginning of the expedition was indeed 175 mm. If it was then already 173 mm, the wire soundings in the beginning were too large, and that error increases with the depth. The differences shown by table II should therefore be smaller (more negative), in consequence of which II—III—IV would more closely approach nil. If, however, all the wire soundings are corrected for a diameter of 173 mm for the measuring wheel, and the differences wire depth minus Atlas depth (table IIa) and again graphically the average differences and also the probable errors of the groups are determined (whereby the group 0 is composed from the shallow depths not included in group 1), then *the same* probable errors are obtained as those of the groups of table II, or even slightly larger, whilst also the number of large deviations has increased.

	Group 0	Group 1	Group 2	Group 3
II	3.7	5.5	7.1	6.6
IIa	3.7	5.5	7.1	6.8

This, to my mind, does not yet solve the question as to what the diameter of the measuring wheel was at the beginning of the expedition.

In order to trace possible errors of a constant character which might have been made during a certain period and not during the further work of the expedition, the differences given by tables II, IIa, III and IV were reduced by the mean differences and arranged in chronological order. The result is to be seen in tables V, Va, VI and VII.

These tables have been divided into four periods, the last three being demarcated by dockings and repairs.

The course of the differences Wire-Atlas, Therm.-Atlas and Wire-Therm. according to the tables V, VI and VII, points out, taking into account the possible inaccuracy of the differences, that if there is a change with the time at all, that change in any case is small.

Table Va, on the other hand, shows that the difference wire-Atlas according to table IIa varies considerably with the time. IIa has apparently been obtained by applying wrong corrections. The supposition that the diameter of the measuring wheel was 173 mm already at the outset is likely wrong; it must have been 175 mm.

Finally it was investigated whether the use of different sounding wires may have led to errors of a constant character; also this appeared not to be the case, but it seems that the soundings with the winding machines for serial observations (swivelled measuring wheel of large diameter) are more accurate than those with the Lucas machine.

It has not, therefore, been found that during a certain period errors of a constant character have been made which were not made during other periods. We therefore can not do otherwise than ascribe the remainders found to inaccuracies of the measurements, caused by *inconstant* errors, so that the results of tables II, III and IV must be adjusted according to the theory of probabilities.

Adjustment gives the following result:

	Table	Group 1	Group 2	Group 3
Comparisons in observations:	II III IV	— 9 —39 +15	—11 —47 +14	—13 —46 + 1
Remainders:		+15	+22	+32
Probable errors non-adjusted groups: .	II III IV	5.5 5.7 3.0	7.1 4.7 3.1	6.6 6.3 1.9
Weights of non-adjusted groups: . . .	II III IV	17 16 56	10 23 52	12 13 140
Corrections:	II III IV	—6 +7 +2	—14 + 6 + 2	—16 +15 + 1
Differences in the adjusted groups: .	II III IV	—15 —32 +17	—25 —41 +16	—29 —31 + 2
Weights of the adjusted groups:	II III IV	29 29 64	26 32 58	24 24 141
Probable error for a diff. with weight 1:		35	53	72
Probable errors of the adjusted groups:	II III IV	6 6 4	10 9 7	15 15 6

The adjusted differences between wire, Atlas and thermometrical depths have been plotted graphically in fig. 4 as functions of the depth. This graph also includes the average difference with the Hughes soundings as deduced from table VIII.

The corresponding lines are very inaccurate, the best determinated difference being still that between wire and therm. depths. Considering that the Atlas line really consists of two non-related parts, one for the D soundings and one for the A soundings, which are separated from each other at about 1000 metres, then, allowing for the inaccuracy of the Atlas line, figure 5 gives a better, more simplified picture.

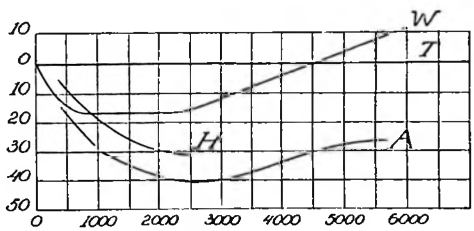

Fig. 4.

From the probable errors of the adjusting groups W—A, T—A and W—T there may be deduced, although inaccurately, the probable error of one wire, Atlas and thermometric depth. For the

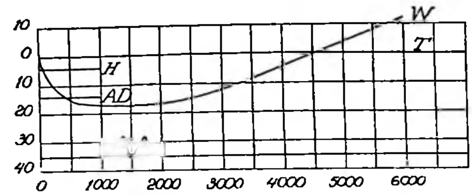

Fig. 5.

present the very rough approximation suffices that the probable error of one wire sounding at a favourable opportunity is about 10 m, that of the Atlas echo distance 20—30 m, that of the therm. depth about 3 m; the weight of a thermometrical depth is thus about 10 times that of the wire depth (by favourable opportunity) and about 70 times that of the echo distance.

As already remarked, the representation given by fig. 5 is very inaccurate, so much so that it would not be justified to attach much value to it were it not that it agrees precisely with the picture of the deviations previously given, a picture which originated during the expedition, independently of what has been arrived at here.

There is not a single reason to assume that on the average the thermometer soundings would not give the right depth. On bottom being reached the sounding machine stopped, in most cases, immediately, and the adaptation time in the basins with almost homothermal water at a greater depth than 800 m must have been sufficient in every case. Errors which are proportional to the depth can only have been small. Consequently it may be assumed that the differences in respect to the T line correspond with the errors in depth. In the case of the wire soundings, owing to the various depth currents and the manoeuvring of the ship the wire is curved, principally in the uppermost couple of hundred metres, as a result of which the wire depths, even the shallow ones, are generally too large. At depths of more than 600 m the depth currents are not so strong by far as those above that depth, and the error caused by the apparent slip neutralizes the excess depth measured as a result of curvature and inclination below the 600 m; at still greater depths the apparent slip predominates. The Atlas A soundings give on an average 35 m too much, which corresponds to the average reaction time given by the Signal Gesellschaft. With the D soundings the reaction time is shorter, because the sharper and shorter sound incites the ear to quicker reaction; the result of the soundings in the Kaoe bay, where there are no depth currents and the ship was lying still while the soundings were taken, points in the same direction.

When the wire sounding, reduced by the mean difference W—T according to the graph, tallies well with the thermometer sounding, then the true depth can be approximated fairly accurately. The differences between Atlas depth (after being corrected for reaction time) and "true" depth are given in table IX. Only those wire soundings were used which were taken while there was no current running, where the wire slanting was practically nil and no abnormal slip was noticed, whilst the Atlas soundings used were all taken above a flat horizontal bottom. From the differences found it appears that there is a probable error in one Atlas echo distance of 24 m, a degree of accuracy corresponding well with that previously deduced for the echo time. The positive and negative differences are each distributed over the whole of the area covered by the expedition.

Our soundings are not accurate enough to decide as to errors in V_m, but anyhow these will not be large, considering the differences between the very deep echo-soundings and the corresponding wire and thermometrical soundings.

An idea of the accuracy of an Atlas sounding with the D transmitter is given by the dispersion shown in table VIII in respect to the mean difference A—H = 10 m. From this dispersion it follows that the probable error in the difference Atlas minus Hughes sounding is 20 m. Taking the probable error of a Hughes sounding to be at least 12 m, the probable error of an Atlas D sounding would be at most 16 m.

The influence of the surface current on the wire depth is indicated by tabel X, the first column of which gives the depths which could be approximated with sufficient accuracy from the thermometrical and Atlas soundings. The wire depths were corrected for the amounts by which they differ on the average according to fig. 5 from the true depth when there is no surface current and the wire is vertical. The third column shows the amounts by which the thus corrected wire depths exceed the approximated depths. From this table it follows that the effect of surface current increases the wire length on an average by 29 m, but that no clear relation can be detected between the strength of

current and the magnitude of the error. If from this table the comparisons are extracted for the cases where the visible length of wire was vertical, then the current correction for these soundings still averages —27 m.

The effect of current on wire soundings is, therefore, considerable, and this confirms the probability of the wire curvature over the first few hundred metres depth as indicated in figures 4 and 5 being of the right shape.

Nothing having become apparent as to the relation between the strength of current and its effect on the wire depth, it has been investigated whether the inclination of the visible end of wire might afford a better indication for the correction to be made (table XI). This table shows that the error in wire depth increases with the deviation of the visible end of wire line from the vertical.

Both in table X and in table XI the differences are independent of the depth; the corrections for the curves below about 600 m depth are apparently already included in the corrections found for the various depths under favourable conditions.

Combining what has been said here regarding the errors in the wire soundings caused by curvature and deviation of the wire from the vertical, which curvature and inclination arise from currents and manoeuvring, it appears that when there was no surface current and the wire was kept vertical our wire soundings were on the average about 20 m too large as a consequence of curves in the top 600 m; that with surface current and the visible end of the wire vertical the curvature gave an average error of +50 m in depth, and that the inclination of the visible end of wire is only of importance when the angle of inclination is large. Almost half of the wire soundings were taken with surface current running and with an angle of inclination of 10° or larger.

Corrections can therefore be made for apparent slip, curvature and the deviation from the vertical by first applying a correction taken from fig. 5 and then, where there was surface current or the visible end of wire was not vertical — or when both were the case, estimating a second correction according to the behaviour of the wire and the tables X and XI. This estimate should preferably be made immediately after bottom has been struck, while the behaviour of the wire is still fresh in the mind.

Table XII gives a summary of comparisons between approximate depths and the wire depths as corrected in the above manner *after the expedition* was ended. This table shows a probable error in wire depth of 23 m, so that the accuracy of our wire soundings is about equal to that of our echo distances.

Frequently, for apparent slip, curvature and angle of inclination of the wire together, one correction is made, based on the deviation of the visible end of the wire from the vertical. This method may quite well be used also for our soundings. On comparing the wire depths corrected in this manner with the approximated depths of table XII, one obtains a probable error in wire depth of 26 m.

Finally, table XIII is a summary of the errors that may be made when the echo distance is taken for the depth in the case of echo sounding over a sloping bottom. Although the effect of the bottom slope averages 11 m (probable error 8 m), the number of times that the depth is too small is hardly more than the number of times the depth is too large. $\frac{2}{3}\sqrt{\frac{\Sigma v^2}{n-1}} = 55$. This confirms that with irregularly sloping sea-floor the effect of the slope may be either that the depth is measured too large or just as well that the depth is measured too small, and it is proved that it is advisable not to include the echo soundings above sloping bottom in the comparison with the other soundings.

CONCLUSIONS:

a. WIRE SOUNDINGS. The corrections for measuring wheel and wire thickness are not definitely established for the first 130 stations. Presumably at the time of departure from Holland the corrections were —1.7 °/₀₀ when using stranded wire of 1.55 mm, and —4 °/₀₀ when using piano wire of 1.0 mm. From station 130 onwards these corrections were —13 and —16 °/₀₀ respectively.

The corrections for elongation are of no importance.

The correction for apparent slip could only be inaccurately determined; comparison with thermometrical and echo soundings leads to a correction of + 9°/₀₀.

Under favourable conditions, i.e. when the visible end of wire while running out and drawing out the sounding tube (or lifting the snapper) was kept properly vertical and there was no surface current running, our wire depths were affected by the submarine currents to an extent, on the average, of about +20 m. Where conditions were not favourable for wire soundings but nevertheless the wire could be kept vertical curvature in the line caused the wire length to be on an average about 45 metres too long. Where surfacecurrent and inclination of the visible end of wire occur together, the wire lengths as a consequence of curvature and inclination of the wire line are on an average about 50 m too long; these curves in the wire are in the top 600 metres.

Our wire soundings taken under favourable conditions had a probable error of about 10 m. Half of our wire soundings, after being corrected as well as possible, still have an error larger than about 25 m.

b. ATLAS SOUNDINGS. Taken over flat horizontal sea-floor, the Atlas A soundings are on an average about 35 m too large, whilst moreover half of the soundings are affected by an error larger than 25 m. The errors in the D soundings are smaller than those in the A soundings, and those in the Hughes soundings are still smaller.

With a uniform slope in the sea-floor the depth is equal to the echo distance x secans of angle of slope. With unevenly sloping bottom the depth may be either less or greater than the echo distance. If no correction is made for bottom slope large errors may result, but this was seldom the case because steep slopes rarely occur. Half of the sea-floor slopes are less than 1½°, 15 % have a slope larger than 6° and 1 % exceed 20°.

E. SHIP'S RECKONING.

a. THE ASTRONOMICAL RECKONING.

A complete reckoning is made by observing simultaneously 4 celestial luminaries differing from each other by about 90° in azimuth, or, when the ship is riding at anchor, also by observing successively the various positions taken up by one celestial luminary on its path across the heavens. The various altitude lines obtained check each other and together give an idea of the accuracy of their position and of the joint result, that is to say of the astronomically fixed position.

The dawn and twilight reckoning was always made by two observers, each making his own complete reckoning whenever possible.

The noon altitude was taken by at least two observers. The noon position was fixed by combining the noon altitude with an observation taken at about 11 o'clock by the officer of the forenoon watch and another taken at about 13 o'clock by the officer of the afternoon watch.

Time signals from Malabar were taken regularly.

Preferably at about midnight the 200 m line was crossed in order to correct the dead reckoning.

For determining the accuracy of the reckonings of the Snellius expedition data were collected which, though not being large in number, owing to the lack of time and opportunities, nevertheless give an idea of the accuracy attained.

When the ship's position was accurately known, either from compass bearings or from angles on well-fixed points, the five observers measured the sun or star altitudes. These observations were made in all possible weathers, unless conditions were so unfavourable that the observations could not be expected to be of much use for correcting the dead reckoning. This procedure was begun immediately after leaving Holland, thus before the observers had had any special training.

If the observation is absolutely correct and the sextant used is faultless, the calculated distance from the accurately known place of observation to the altitude line should be nil. If the result of the observer's reckoning is the amount + a, then he has made an error of + a in his measurement of altitude and his reckoning has to be corrected by — a.

These determinations of the "error in p" were supplemented by amounts deduced from observations on several anchoring stations where the position of the ship was fixed not on terrestrial points but from the astronomical reckoning itself. Then, however, the position of the anchored ship had to be known exactly from a very large number of altitude lines.

The first kind of determinations of the "error in p" gives a too unfavourable picture (they included also observations in the Red Sea), whilst the second kind gives a too favourable picture.

As to the altitude corrections, the deviations in the angle of diffraction due to atmospheric pressure and temperature are so small for the East Indian Archipelago, according to the tables, as to be negligible, and the deviation in dip of the horizon was repeatedly checked with the Pulfrich instrument and always found to be nil (with one exception, off the Maldives, where the deviation was ¾'). Apparently, therefore, abnormal dip of the horizon does not occur in the Archipelago, or only very rarely.

As a result of observations on the sun and stars and for all 5 observers, 131 determinations were made of the error in p, as given below. The first and third lines give the error in p in tenths of a minute, the second and fourth lines indicating the number of times the error was made.

+	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	+0
	2	0	2	2	0	1	1	2	1	2	1	2	0	1	4	3	5	2	3	2	12	6	6	7	5	15
—	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	—
	0	0	0	1	0	1	1	0	0	1	3	1	1	0	1	2	0	3	2	3	4	3	7	7	3	

If the magnitude of error is set out along the horizontal axis and the number of times that error was made along the vertical axis, and the resultant *frequency curve of the error in p* is levelled out to a tallying line, then a picture is obtained as given in fig. 6.

From this table or from the curve it appears that on the average a constant error of + 0.2'

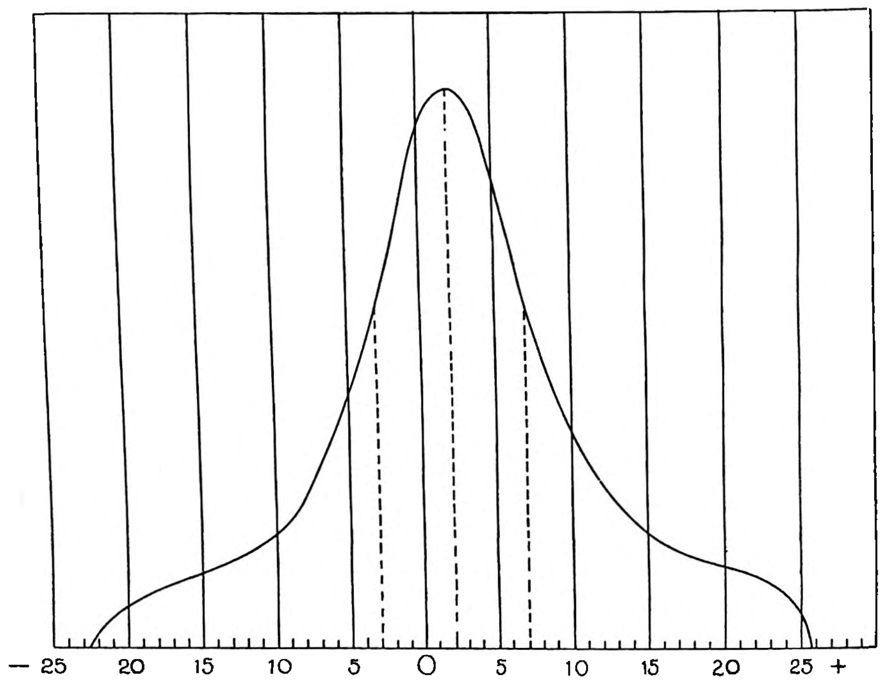

Fig. 6. Frequency curve of the error in p.

was made, that 50% of the observations gave errors in p between + 0.7 and — 0.3' and that the maximum errors were + 2.5' and — 2.2'.

From the observations made it further appears that the altitude line of a star (determined in twilight) is about 1½ times as accurate as that of the sun, that two observers made a constant error (personal error + error of their instruments) of about + 0.4', and that the constant error of the others was about nil.

A constant error of 0.4' is so great that really a correction should be made for it, but the difficulty is to ascertain whether that error is of a temporary or a permanent nature. If the fault lies in the sextant this can be allowed for, but if it lies with the observer it may be due to a temporary defect of the eyes. The constant character can only be seen from observations made during a long period, and then it is generally too late to make corrections.

In order to demonstrate what can be achieved with astronomical observations the errors in p of the best observer are given (36 observations):

Error in p (in tenths of a minute):	— 15	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	14 +
number of times the error was made:	2	1	1	1	1	1	3	1	1	8	3	3	2	2	2	2	1	0	1

to which it is to be added that the errors —1.5′ (twice) and + 1.4′ were made in the first month after departure from Holland, before any intensive trainig had been had.

An insight into the accuracy of the astronomical reckoning was also obtained in another way. In the twilight reckoning it frequently occurred that the altitude of one and the same star was determined by two observers simultaneously. From the differences with the average the probable error of one observation can be determined, although a too favourable picture is obtained. On the other hand, however, no use has been made of the noon altitudes, the determinations of which as made by the varoius observers did not, on the whole, differ very much. Neither are there included here the special observations already used in the foregoing table and in the curve.

The result is 177 differences in p, as given below, which show a probable error of r = 0.68′.

Difference:	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	5	10	4	6	12	7	8	11	6	13
Difference:	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
	6	8	5	5	6	4	3	2	4	2
Difference:	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
	5	5	5	2	1	1	1	0	4	2
Difference:	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9
	1	2	1	3	1	2	1	3	3	0
Difference:	4.6	4.9	5.0	5.9	6.5	7.3	7.7			
	1	1	1	1	1	1	1			

It appears that 50% of the twilight observations made during the whole time of the expedition are affected by an error smaller than 0.68′. It is to be borne in mind that these also include observations made under absolutely unfavourable conditions. During the east monsoon the horizon and the stars were often hazy. At the turn of the monsoons the horizon, when the water was dead calm, was very badly visible. And in the west monsoon the horizon was again often bad and only a glimpse could be caught of the stars between the clouds. It then also occured that the stiff wind blowing over the open bridge made it very difficult to take observations at all. These are all circumstances which were not so strongly pronounced in the observations first dealt with, so that on that account the result must be somewhat more unfavourable.

A remarkable case occured in observing the noon latitude near Tg. Goram, near N.-point of Halmaheira. The atmosphere was very clear and the horizon and edge of the sun stood out exceptionally clear. The ship's position was most accurately fixed by compass bearings on points close at hand, ant the chart of that vicinity is absolutely reliable. The latitude of the sun as taken by 5 observers was respectively 0.9, 1.8, 0.9, 0.5 and 1.5 minutes too high. One would be inclined to account for these errors by abnormal dip of the horizon or by false horizon, but such is most improbable, because half the sum of the horizon dips in the direction of the sun and opposite thereto were checked up with the Pulfrich instrument and found to be equal to the normal horizon dip.

I experienced a similar case on a survey between Misool and New Guinea, when we had to work partly on astronomical reckoning. At about 11 o'clock 5 observers noted a transit of Venus giving a difference of three nautical miles from the noon latitude. No current had ever been observed in that vicinity, the observers were all well-trained, the observations did not differ from each other to any extent worth mentioning, the atmosphere was quite clear and the horizon stood out exceptionally sharp. Under these conditions very good results were to be expected, and not a difference in latitude of 3 miles.

Similar cases were recorded in longitude observations taken on the sun near Siaoe and by twilight observations off the N. coast of Wetar. Such deviations, which only occur with very clear atmosphere, are presumably to be ascribed to abnormal refraction in the high layers of atmosphere.

Generally speaking, the impression was that the altitude lines of one and the same star as determined by two observers often lay on the same side of the apparant position. Fixing of the astronomical position by more than two persons will not, therefore, yield a very much more accurate result than a determination by two observers, and then the advantage of two observers observing

and ciphering quite independently of each other lies mainly in the chance of a mistake being greatly reduced.

From the observations of the Snellius Expedition dealt with above, the following *conclusions* may be drawn:

1. Abnormal dip of horizon hardly ever occurs in the East Indian Archipelago.

2. There is no use in making small corrections such as those in tables for the deviation from the normal refraction.

3. Altitude measurements are sometimes affected by a considerable error which is not to be ascribed to faultly observation, but presumably to abnormal refraction in the high layers of atmosphere.

4. In most cases there is no advantage in having reckonings made by more than two observers.

5. The personal error of the observer may be so great that a correction should be made for it.

6. Anyone having a natural aptitude for observer's work can become so proficient that, given normal conditions, the error in his observations amounts to at most 45'', with a 50% chance that it is even less than 10''; for this reason it is well that the navigating sextant is graduated in parts of 10''.

7. As an average, 50% of the altitude lines of the Snellius expedition fixed under not unfavourable conditions have an error in p less than 0.6'; the maximum error for these cases may be taken to be 2.5'.

8. As an average, 50% of the altitude lines of the Snellius expedition spread over the whole duration of the expedition have an error less than 0.7'; the maximum error observed was about 4'.

9. For determining the accuracy of a certain fixed point the above amounts may only be used with reserve, and that accuracy must be deduced from the mutual position of the determining altitude lines.

10. If an average value is required for the accuracy of the astronomically fixed points of the Snellius expedition, then for the whole astronomical position-finding it may be taken that there is a 50% chance that the true position lies within a circle on a radius of 0.4' from the apparent position; for the noon reckoning this may be taken at 0.5—0.6'.

An error larger than 2' will be only very exceptional.

b. FIXING POSITION WITH REFERENCE TO TERRESTRIAL POINTS.

In contrast to the astronomical fix, where the apparent place is found on longitude and latitude, with compass bearing, Snellius and astronomical bearing the ship's position is fixed with reference to land marks.

The systematic survey of the East Indian Archipelago as far as regards the explored area was as good as completed at the time that the expedition was there. For the few parts which had not yet been surveyed the necessary data could be obtained before the fair sheets were worked out; it may, therefore, be assumed that the landmarks of our archipelago which were used for position-finding are well related and fixed for longitude and latitude. The small errors attaching to every survey are so minute that they need not be considered here.

With the Philippines the case was different. Off Sibutu we observed considerable deviations from the chart.

1. *Compass bearing.* The Snellius was equipped with only magnetic compasses with ordinary wire sight.

The accuracy of the compass bearing is affected by the varying conditions more than the astronomical reckoning. With favourable weather and recently verified compass error, the accuracy depends only on the accuracy of the reading. Owing to the rather imperfect arrangement of the wire sight readings could not be taken with a greater accuracy than $\frac{1}{2}°$, so that there is just as much chance of an error being made larger as smaller than $\frac{1}{4}°$. This is the accuracy that one has in determining the compass error and in taking the bearings; in that favourable case the probable error of the bearing direction is 0.35°. It is assumed that the error in variation is so small as to be negligible.

If the compass error has not been verified for a long time, or if there have been particular circumstances considerably changing the magnetic position since the last verification, the bearing may be out by a few degrees.

With rolling or pitching ship the compass card is apt to rock badly, even if the compass is properly mounted and balanced. In such an event the compass bearing may be so rough that only a small value can be attached to the positions obtained.

If an attempt is made to give an average value for the accuracy of the compass bearing, that can only be but a very rough approximation.

An idea of the deviation errors which may occur with a good compass is given by the following table of differences: new compass error minus old compass error, according to successive error determinations of the Snellius compass. The differences are expressed in quarters of a degree.

Difference:	0	+ 1	2	3	4	5	6	7	8	9	10	11	12	13
Number of times:	14	7	7	5	7	3	2	3	1	2	0	3	1	2
Difference:		— 1	2	3	4	5	6	7	8	9	10	11	12	13
Number of times:		7	16	7	4	5	3	3	2	1	0	0	0	2

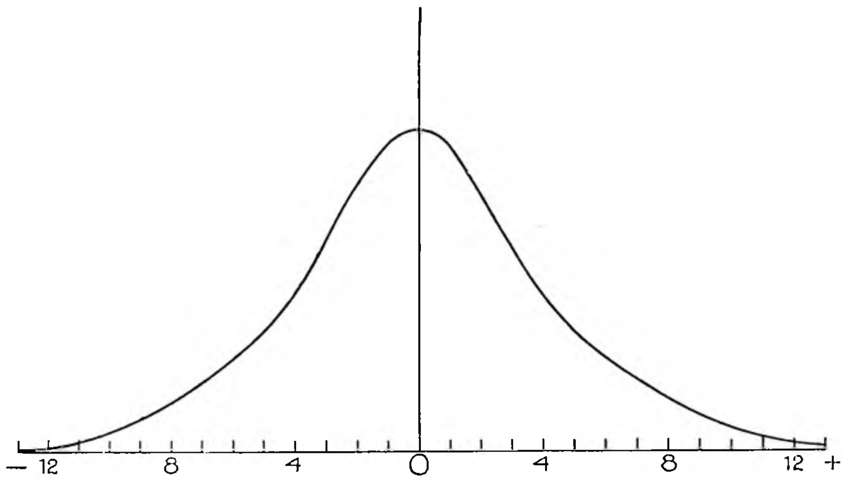

Fig. 7. Frequency curve new compass error minus old compas error.

It is to be noted that these differences include those found by error determinations after the ship had been in repair; this accounts for the very big differences. If from these values a frequency curve is plotted, from which the very big differences may certainly be omitted, we get the line shown in fig. 7.

Supposing that in determining the error the compass error 0 is found for the course North and that the error on that course some time later is found to be + 2, then if bearings have regularly been taken during that period while the ship was on a northerly course and the compass error on that course and in that time has gradually changed, the compass error 0 will have been applied on that northerly course whilst actually it will have been 0.1, 0.2, 0.3 . . . 1.9, 2.0. Of the errors thereby made there will have been just as many larger as smaller than 1°.

In accordance with the foregoing, if those suppositions are correct, one may arrive at a probable error in the deviation of the Snellius compass during the expedition which is the average of half of all the deviations given in the above table. A probable error of $\frac{1}{2}°$ is then found.

Actually the position is more favourable. If there is no reason to suppose that the errors of the compass have altered very much, the compass error is only fixed anew for the course that will be followed for some time. Most bearings, however, will be taken on that very course. Only when various courses have to be followed, as occurs in the special surveying of an area, while manoeuvring and while navigating amidst dangers, will the compass errors applied have, as a rule, an inaccuracy indicated by a probable error = $\frac{1}{2}°$. On the other hand it is just for that case that an accurate fixing of position is important.

If the bearings can then be taken accurately, the probable error of the bearing direction can be put at $\sqrt{(\frac{1}{2})^2 + (\frac{1}{4})^2} = 0.6°$, but if the compass card is badly rocking the bearing direction will be only half so accurate, so that then the probable error will be $\sqrt{(\frac{1}{2})^2 + (\frac{1}{2})^2} = 0.7°$.

We found, more or less by reasoning and from values obtained in practice, that the bearing direction of the Snellius expedition has a 50% chance of being affected by an error less than 0.35, 0.6 and 0.7° according to whether the circumstances were more or less favourable; exceptionally unfavourable conditions excluded.

For a comparison with the astronomical reckoning it is necessary that the angular error in observation is converted in a linear displacement perpendicular to the bearing line near the ship at the known distance of the bearing mark. This is found in the following table:

Distance from ship to bearing mark (miles)	Problable errors (in metres)		
	Favourable conditions	Less favourable conditions	Unfavourable conditions
5	60	100	110
10	110	190	230
15	170	290	340
20	230	390	460
25	280	490	570
30	340	580	680
35	400	680	800
40	450	780	910
50	570	970	1130
60	680	1160	1360
70	790	1360	1580
80	910	1550	1810

For the error in the bearing line charted near the position of the ship this table gives values of such magnitude that under successively favourable, less favourable and unfavourable conditions there is just as much chance that the deviation will be larger as smaller than those indicated.

With the aid of these figures comparisons may be made between the average accuracy of the individual bearing line and that of the individual altitude line. For a comparison between the accuracy of the compass bearing and that of the astronomically fixed position, account is to be taken not only of the number of bearing lines and altitude lines and their azimuthal deviations, but also of the fact that with the compass bearing the deviation error is a constant one, which is often larger than the variable error and which is mostly not eliminated, because the bearing marks generally are all on one side.

It frequently occurred that the landmarks were on an extended coastline and the extreme bearing directions differed about 90° from each other. Where the deviation error was predominant it may be taken that the error in the supposed position of the ship is at least just as great as the error in position of one of the bearing lines.

Bij rough approximation, to form some idea, it may be said that at 35 miles distance from the coast the probable error of such a compass bearing is between 450 and 910 metres. This degree of accuracy is somewhat smaller than that of the astronomical reckoning, whilst the distance of 35 miles from the coast is also about the mean limit within which land could be sighted. As a *rough rule* it may therefore be taken that *the compass bearing on an average is more accurate than the astronomical reckoning.*

2. With the method of *Snellius* (Pothenot) the position-finding was done in combination with compass bearings on a with certainty recognised mark. The differences in direction were then set out on a piece of tracing paper, which was laid on the chart and all measurements made to tally. In this way there is little chance of wrong marks being used, and a very accurate position is obtained.

F. ACCURACY OF THE DEEP-SEA CHARTS.

As regards the fair sheets, these have been dealt with in volume I, chapter C. For the compilation of the deep-sea charts use was also made of the echo soundings of the "Emden", "Karlsruhe" and "Köln", whilst the survey of the Sangihe group was also received in good time and, further, use could be made of the new American, English and German charts. With the exception of a stretch of the 200 metre line near the Aroe group, the coast-line and the depths up to 200 metres were surveyed systematically.

As to greater depths, the charts are based mainly on the Snellius echo soundings and on wire line soundings. The accuracy of the chart depends on the accuracy of the soundings and fixing of position, on the time that elapsed between the position-findings, and on the variation in strength of current. If it is required to know the accuracy of a certain depth figure or a certain spot, the original data have to be studied. Here only the accuracy of the chart as a whole can be given approximately.

The echo distances measured with the Atlas A sounder are on the average about 35 m too large. Those measured with the Atlas D sounder are presumably subject to a smaller error, but the D sounder could only be used for depths not exceeding 1000 m, and moreover for soundings between 200 and 1000 m often an A sounder was used; the D soundings are therefore comparatively few in number. The number of Hughes soundings is still smaller, so that, practically speaking, account need only be taken of the Atlas A soundings.

Half of the wire soundings taken by the Expedition are about 20 m too large owing to the effect of submarine currents and manoeuvring, the other half being about 50 m too large as a result of surface current, submarine currents and manoeuvring together. On the average, therefore, the correction for curvature and inclination from the vertical is about —35 m. It may be taken that the same applies for the wire line soundings used for the chart, and that those soundings have not been corrected for curvature and inclination. Consequently, as an average, all the soundings of more than a few hundred metres are about 35 m too large.

The echo soundings have not been corrected for bottom slope. As a consequence errors have been made which for about 15 cases out of a hunderd are greater than 15 m and greater than 5°/₀₀ of the depth, and for about 7 cases out of a hundred greater than 30 m and 1% of the depth. Although considerable errors may have been made by not correcting for bottom slope, large errors occur so seldom, relatively speaking, that the mean inaccuracy is only slightly affected thereby. Furthermore, where the sea-floor is terraced and undulating, among the soundings taken over a slope there are some taken over the terraces, peaks and basins where the bottom slope is small or nil. For the probable error of an echo distance we found 24 m, and for that of a wire line sounding about the same amount. Roughly speaking it may therefore be taken that the soundings applied are 35 m too large and that for 50% they are moreover affected by errors smaller than 24 m.

The positions fixed direct by complete twilight reckoning are subject for one half to errors smaller than 0.4', whilst those fixed by noon reckoning are affected for one half by errors smaller than 0.5—0.6'. The positions fixed by compass bearing on the Snellius are on the average more accurate than those taken by the complete reckoning. We shall not, therefore, be far from the truth if we assume that half of the fixed positions are subject to an error less than 0.5' or 926 m.

Fifty per cent of the floor slopes are less than 1½°. With a dip of 1½° a displacement of 926 m perpendicular to the depth line gives a difference in depth of 24 m, or in other words an error in

sounding of 24 m corresponds, where the bottom slope is $1\frac{1}{2}°$, to an error in position of 926 m.

Conclusion. If the soundings are corrected for —35 m the remaining errors have on the average just as great an effect as the errors in the fixing of position. The depth figures at the positions fixed, after being reduced by 35 m, are subject to errors which, taken over the whole area covered by the Expedition, may be either more or less than $24\sqrt{2} = 34$ *m in depth or* $926\sqrt{2} = 1300$ *m in position.*

APPENDIX No. 1

VELOCITIES OF SOUND IN SEA WATER

TABLE 4

Eastern Part Netherlands Indian Archipelago.

Depth (metres)	t °C	S ‰	$10^8 \times \mu$	Pression (decibars)	Correction to be added to Table 2	Depth (metres)	t °C	S ‰	$10^8 \times \mu$	Pression (decibars)	Correction to be added to Table 2
100	23	34.4	4271		1.8	3900	3.1		4297		69.7
200	14.5	34.6		201	3.6	4000				4068	71.5
300	11		4393		5.4	4100	3.1		4285		73.5
400	9			402	7.2	4200				4273	75.0
500	8		4452		9.0	4300	3.1		4271		76.8
600	7			604	10.8	4400				4479	78.6
700			4460		12.7	4500	3.2		4258		80.3
800	5.5			806	14.5	4600				4684	82.0
900			4462		16.4	4700	3.2		4244		83.8
1000	4.7			1009	18.2	4800				4890	85.6
1100			4462		20.0	4900	3.3		4231		87.3
1200	4.1			1211	21.8	5000				5096	89.2
1300			4459		23.5	5100	3.5		4219		90.9
1400				1414	25.2	5200				5303	92.7
1500	3.6		4455		26.9	5300	3.3		4206		94.4
1600				1617	28.6	5400				5509	96.1
1700	3.3		4445		30.3	5500	3.3		4192		97.9
1800				1820	32.0	5600				5716	99.7
1900	3.3		4434		33.7	5700	3.4		4180		101.5
2000		34.6		2024	35.6	5800		34.6		5923	103.2
2100	3.2		4422		37.4	5900	3.4		4166		104.9
2200				2227	39.2	6000				6130	106.7
2300	3.2		4407		41.0	6100	3.4		4152		108.4
2400				2431	42.8	6200				6337	110.1
2500	3.2		4394		44.6	6300	3.4		4138		111.9
2600				2635	46.4	6400				6544	113.6
2700	3.2		4379		48.2	6500	3.5		4124		115.3
2800				2839	50.0	6600				6752	117.0
2900	3.2		4366		51.8	6700	3.5		4111		118.8
3000				3044	53.6	6800				6959	120.5
3100	3.2		4352		55.4	6900	3.6		4098		122.2
3200				3248	57.2	7000				7167	123.9
3300	3.2		4338		59.0	7100	3.6		4085		125.6
3400				3452	60.8	7200				7375	127.3
3500	3.2		4325		62.6	7300	3.6		4072		129.0
3600				3657	64.3	7400				7583	130.7
3700	3.2		4311		66.1	7500	3.6		4059		132.4
3800				3862	67.9	7600				7792	134.1

TABLE 4

Sulu-sea.

Depth (meters)	t °C	S ‰	$10^8 \times \mu$	Pression (decibars)	Correction to be added to Table 2	Depth (metres)	t °C	S ‰	$10^8 \times \mu$	Pression (decibars)	Correction to be added to Table 2
100	24.4	34.3	4193		2.0	2300			4269		40.5
200	15.8	34.5		200	3.8	2400				2428	42.3
300	12.9		4277		5.6	2500	10.2		4255		44.0
400	11.9			401	7.2	2600				2632	45.8
500	11.1		4375		9.1	2700			4242		47.6
600	10.6			603	10.8	2800				2835	49.4
700			4374		11.6	2900			4228		51.1
800	10.2			805	13.3	3000	10.3			3039	52.9
900			4364		15.1	3100			4214		54.7
1000	10.1			1008	17.0	3200				3243	56.4
1100			4352		18.8	3300			4201		58.2
1200	10.1	34.5		1210	20.7	3400		34.5		3448	59.9
1300			4338		22.5	3500	10.4		4187		61.6
1400				1412	24.3	3600				3652	63.2
1500	10.1		4324		27.0	3700			4176		65.0
1600				1615	27.9	3800				3857	66.7
1700	10.1		4311		29.7	3900			4152		68.5
1800				1818	31.5	4000	10.4			4062	70.2
1900			4297		33.3	4100			4117		72.0
2000	10.1			2021	35.2	4200				4267	73.6
2100			4283		36.9	4300			4138		75.4
2200				2224	38.7	4400	10.5			4472	77.0

HORIZONTAL VELOCITIES OF SOUND IN SEA WATER (V_H'S), ACCORDING TO CORRECTED TABLES 2—5 OF THE BRITISH ADMIRALTY

Sea	Date	Sta-tion	Latitude	Long-itude E	Depth 0	25	50	75	100	125	150	175	200	250	300	400	500	600	700	800	900	1000	1250	1500	1750	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8500	100
Eastern part Java sea	27 VII 29	25—28	±6—00 S	114—30	1534.2	1534.8	1534.6																																
Strait Makasser....	30 VII 29	30	04—43 S	117—50	1534.4	1535.7	1534.9	—	1526.1	—	1510.0	1503.1	1499.4	1492.5	1489.0	1487.0	1483.8	1484.4	—	1483.6	—	1483.6	1485.2	1488.5															
	30 VII 29	31	04—42 S	118—15	1535.9	1535.1	1532.9	—	1525.1	—	1510.9	1499.0	1498.8	1496.4	1491.6	1487.4	1486.8	1485.0	—	1482.6	—	1483.4	1486.6	1489.1	1491.4	1494.0													
Celebes sea	13 VIII 29	43	01—17 N	119—54	1539.4	1538.8	1535.1	—	1531.9	—	1515.2	1510.1	1505.1	1501.3	1498.4	1487.0	1484.7	1485.2	—	1483.6	—	1484.0	1486.2	1489.1	1492.3	1497.0	1505.6												
	19 VIII 29	47	02—23 N	119—46	1539.1	1539.7	1538.6	—	1535.2	—	1527.3	1516.9	1505.8	1492.4	1489.0	1487.0	1485.3	1484.6	—	1482.2	—	1484.2	1485.8	1488.7	1492.9	1496.5	1505.6	1514.4	—	1532.5	—	1550.6							
	4 IX 29	57	05—51 N	123—06	1538.3	1538.3	1537.9	—	1532.5	—	1526.5	1518.7	1513.1	1501.7	1496.5	1488.5	1488.5	1485.5	—	1483.6	—	1483.6	1486.2	1489.1	1492.5	1496.6	1505.6	1514.6	—	1532.7									
	21 IX 29	77	02—10 N	124—59	1540.3	—	1537.4	—	1530.0	1524.9	1519.0	1511.7	1508.0	1496.0	1493.3	1489.7	1487.7	—	1487.0	—	—	—	1485.6																
Molukken Passage .	22 IX 29	79	01—50 N	125—41	1537.9	—	1537.2	—	1524.2	1516.6	1507.1	1504.0	1501.6	1494.0	1492.9	1489.7	1485.5	1483.4	—	1484.0	—	1487.9	1483.5	1485.3															
	1 X 29	80	01—07 S	126—44	1538.0	—	1536.7	—	1533.0	1530.6	1521.8	1514.6	1507.9	1502.6	1498.7	1490.0	1489.1	1485.7	—	1484.2	—	1484.6	1484.5	1486.7	1487.8	1491.5	1499.7	1508.3	1517.1										
Boeroe and Ceram sea	5 IV 30	229	02—33 S	126—57	1539.3	—	1538.0	—	1532.1	1527.6	1521.3	1515.8	1510.3	1502.6	1499.4	1491.5	1489.5	1487.0	—	1484.2	—	1485.0	1484.9	1487.4	1491.2	1495.3	1503.4	1512.0	1520.9	1530.2	1539.1								
	2 X 29	84	01—40 S	128—47	1539.7	—	1534.2	—	1528.0	1520.1	1516.6	1511.4	1507.9	1502.6	1497.3	1491.8	1489.1	1486.2	—	1485.0	—	1484.2	1486.2																
	7 X 29	90	02—50 S	131—14	1538.0	—	1536.1	—	1528.3	1522.6	1516.6	1512.3	1508.2	1501.2	1496.1	1490.6	1488.3	1485.8	—	1484.2	—	1483.8	1485.4	1487.9															
Aroe sea	9 X 29	97	04—48 S	133—25	1535.8	—	1532.3	—	1525.9	1524.3	1522.0	1517.2	1510.4	1503.9	1500.0	1494.3	1490.2	1487.0	—	1485.4	—	1485.0	1486.2	1489.6	—	1497.9													
	12 X 29	100	05—52 S	133—21	1535.7	—	1529.6	—	1523.5	1522.1	1518.7	1513.9	1511.3	1503.1	1497.5	1491.4	1487.1	1485.4	—	1484.6	—	1484.6	1486.2	1489.6	1493.3	1497.8	1506.8												
	18 X 29	109	07—54 S	131—47	1536.4	—	1534.6	—	1526.5	1521.7	1517.7	1513.2	1508.1	1503.1	1495.8	1490.6	1487.9	1485.9	—	1484.7	—	1484.6	1485.2	1487.1															
Timor sea	26 X 29	118	09—10 S	127—52	1539.8	—	1535.0	—	1528.2	1523.5	1519.9	1511.8	1511.2	1500.4	1492.5	1489.1	1487.2	1485.0	—	1484.8	—	1484.2	1485.8	1486.7	1489.2	1493.2	1502.2												
Savoe sea	13 XI 29	135	10—12 S	121—20	1537.9	—	1532.6	—	1529.0	1521.9	1518.9	1512.7	1503.8	1495.0	1492.3	1488.2	1486.1	1485.4	1485.2	1485.0	—	1483.8																	
	21 XI 29	142	09—58 S	121—18	1538.9	—	1533.5	—	1528.2	1522.3	1515.0	1507.5	1503.5	1497.9	1493.5	1489.8	1486.2	1485.0	—	1484.6	—	1481.6	1484.9	1487.9															
	9 XII 29	155	09—29 S	122—43	1542.2	—	1530.9	—	1522.0	1518.8	1513.4	1507.5	1501.8	1494.7	1490.6	1488.7	1486.8	1485.6	—	1484.0	—	1483.6	1484.9	1486.7	1491.6	1495.7	1504.7	1513.7											
Bali and Flores sea	30 I 30	173	07—54 S	116—15	1539.5	—	1538.3	—	1522.2	1510.1	1508.3	1505.3	1501.5	1495.7	1494.1	1486.3	1485.5	1483.9	—	1483.1	—	1482.6	1485.0																
	31 I 30	174	07—59 S	117—19	1539.6	—	1532.4	—	1522.4	1517.8	1511.4	1509.1	1506.5	1497.8	1494.5	1488.2	1485.5	1484.0	—	1483.0	—	1483.8																	
	16 VIII 30	313	ditto	ditto	1535.9	—	1537.1	—	1533.3	1527.3	1521.8	1511.6	1503.1	1497.5	1489.3	1486.7	1484.7	1485.0	—	1483.6	—	1484.2																	
	13 II 30	185	05—50 S	119—22	1540.3	—	1537.2	—	1534.5	1532.7	1515.7	1510.4	1507.4	1497.5	1492.3																								
	5 II 30	180	07—47 S	120—07	1538.1	—	1535.6	—	1525.1	1521.9	1512.5	1505.6	1501.5	1495.6	1490.8	1486.9	1484.6	1482.8	—	1482.4	—	1483.4	1485.4	1487.9	1491.2	1495.6	1503.8	1513.3	1522.2	1531.5	1540.3	1549.4							
	6 II 30	181	08—05 S	120—14	1542.1	—	1532.0	—	1524.4	1518.5	1514.4	1513.4	1506.1	1493.1	1488.9	1486.7	1484.7	1483.2	—	1483.6	—	1483.2	1485.2	1487.9	1491.2	1495.3	1503.8												
	18 VIII 30	314	ditto	ditto	1535.1	1535.9	1536.3	1536.3	1536.6	1528.0	1512.9	1508.4	1501.1	—	1489.4	1487.0		1483.6	—	—	—	1483.4	—	1486.9	—	—													
	14 II 30	187	06—17 S	120—46	1536.1	—	1537.3	—	1527.4	1521.1	1515.9	1506.3	1502.1	1496.1	1492.7	1488.9	1485.5	1483.4	—	1483.4	—	1483.8	1485.4	1489.1	1493.3	1497.8	1506.8	1516.3											
	16 II 30	191	04—19 S	121—03	1540.7	1540.6	1540.4	1538.2	1531.6	1525.3	1519.2		1506.2	1497.5	1493.4	1488.6	1485.8	1484.6	—	1483.8	—	1483.4	1485.4	1487.9	1491.2														
Banda sea	17 XII 29	164	07—28 S	124—27	1539.6	—	1533.8	—	1525.2	1521.7	1516.5	1509.5	1505.8	1497.8	1495.9	1489.3	1486.3	1484.6	—	1483.4	—	1484.2	1485.4	1487.9	1491.2	1495.3	1503.4	1512.4	1521.3										
	9 III 30	205	07—02 S	125—13	1538.2	—	1536.4	—	1530.9	1524.7	1518.1	1508.5	1504.2	1495.0	1493.6	1492.1	1487.5	1485.7	—	1484.6	—	1484.2	1485.4	1487.9	1491.2	1495.3	—	—	—	1530.2									
	15 III 30	212	03—30 S	124—33	1540.1	—	1540.0	—	1532.1	1527.6	1521.8	1513.0	1507.8	1496.6	1495.1	1493.2	1490.9	1487.0	—	1483.4	—	1483.8	1485.4	1487.9	1491.2	1495.3	1503.4	1512.4	1521.3	1530.2	1539.4	1548.2							
	8 IV 30	235	05—17 S	129—15	1539.3	—	1539.0	—	1528.0	1517.8	1512.0	1509.1	1504.5	1498.4	1493.0	1487.6	1485.3	1485.8	—	1484.6	—	1484.2	1486.2	1487.9	1491.2	1495.3	1503.4	1512.4	1521.4	1530.2	1539.4	1548.8							
	18 IV 30	253	03—31 S	127—25	1539.2	—	1538.4	—	1529.4	1521.1	1517.3	1510.7	1500.9	1493.9	1490.4	1487.9	1488.3	1483.8	—	1483.8	—	1483.4	1484.9	1487.4	1490.8	1495.3	1503.8	1512.8	1521.7	1529.7									
Weber deep	3 IX 30	321	04—45 S	130—42	1532.2	—	1530.2	1521.6	1519.5	1517.5	1514.8	—	1506.8	1495.9	1495.1	1490.6	—	1488.0	—	1484.6	—	1484.4	1485.8	1488.3	—	1495.3	1503.4	1512.4	1521.3	1530.6	—	1548.6	—	1566.5					
	22 X 30	362	05—35 S	130—56	1536.0	—	1530.7	1524.0	1522.4	1517.9	1513.9	—	1506.8	1501.5	1498.2	1492.1	—	1485.8	—	1483.8	—	1483.4	1485.4	1487.9	—	1494.8	1503.4	1512.4	—	1530.6	—	1548.6	—	1566.5	—	1584.6			
	27 X 30	369	07—24 S	129—17	1538.4	—	1532.0	1525.0	1521.7	1519.1	1515.6	—	1508.1	1501.8	1497.2	1491.0	1486.2	1485.4	—	1484.2	—	1483.0	1485.4	1487.9	1491.2	1495.3	1503.4	1512.4	1521.3	1530.6	1539.4								
Average V_H's Ind. Arch.					1538.1		1535.3		1527.9	1522.2	1516.6	1510.5	1505.6	1498.0	1494.0	1489.2	1486.8	1485.1		1483.9		1483.9	1485.5	1487.9	1491.7	1495.8	1504.4	1513.2	1521.4	1530.8	1539.5	1549.0		1566.5		1584.6			
Sulu sea	6 IX 29	64	07—41 N	121—02	1537.1	1537.3	1537.2	—	1531.5	—	1517.0	1511.9	1509.7	1504.2	1502.1	1500.5	1499.4	1499.2	—	1500.2	—	1503.5	1508.1	1512.5	1517.1	1521.9	1530.9	1540.3	1549.1	1558.3									
	9 IX 29	71	04—52 N	119—41	1537.1	1536.2	1534.6	—	1524.9	—	1504.4	1504.4	1502.3																										
Emden deep	16 V 30	262	09—42 N	126—52	1540.0	—	1540.0	—	1535.4	1530.0	1522.7	1514.4	1508.7	1499.6	1494.0	1488.6	1484.7	1484.0	—	1483.2	—	1483.4	1484.3	1486.4	1488.9	1491.6	1498.5	1507.2	1515.7	1525.6	1533.4	—	1551.8	—	1569.7	—	1587.2	1605.4	1632.2
Indian Ocean	8 IX 29	131	11—44 S	122—01	1540.8	—	1534.9	—	1526.3	1518.3	1511.4	1507.6	1505.2	1500.8	1496.8	1490.3	1488.3	1486.2	—	1485.0	—	1484.6	1486.2	1487.0	1488.9	1491.7	1499.1												
	11 IX 30	382	12—10 S	119—51	1542.3	—	1536.4	—	1531.7	1529.5	1519.3	1512.8	1507.1	1497.7	1494.7	1489.9	1487.5	1486.3	—	1484.7	—	1485.0	1486.2	1487.7	—	1492.6	1499.5	1506.8	1514.0										
	24 IX 29	145	11—09 S	119—18	1539.2	—	1531.3	—	1523.2	1518.1	1513.8	1506.2	1501.8	1495.0	1493.0	1488.6	1486.8	1485.0	—	1484.2	—	1484.2	1485.8	1488.3	—	1492.6	1499.5	1507.2	1514.3	1522.8	1531.7	1540.6	1549.8						
mean Pacific and Ind. Ocean					1541		1536		1529	1524	1517	1510	1506	1498	1495	1489	1487	1485		1484		1484	1486	1487	1489	1492	1499	1507	1515	1524	1533	1541	1551		1570		1587	1605	1632
Mediterranean	29 III 29	10	37—12 N	006—55	1501.1	—	—	—	1504.8	—	—	—	1505.3	—	1507.6	1509.2	—	1512.5			1517.6					1541.6	(2251)												
	31 III 29	11	36—38 N	012—57	1502.6	—	—	—	1504.4	—	—	—	1509.1	—	1511.9	1512.4	—	1515.6			1521.0	1524.3	(1083)																
	1 IV 29	12	35—13 N	017—00	1507.7	—	—	—	1507.5	—	—	—	1511.7	—	1512.6	1513.4	—	1515.7	—		1520.0							1561.3	(3225)										
	3 IV 29	14	33—06 N	024—28	1510.5	—	—	—	—	—	—	—	—	—	—	—	1513.1	—	—	—		1521.5		1530.1	1538.7 (1950)														
Red sea	15 IV 29	16	22—56 N	037—12	1538.8	1537.8	1536.6	—	1537.8	—	1538.6	—	—	1536.9	—	1536.3	1538.2	1540.0	1541.8		1545.4	1548.5	(1079)																
	16 IV 29	17	19—48 N	039—09	1544.5	1540.5	1539.9	—	1538.9	—	1534.0	—	1533.5	1533.5	1534.5	1535.8																							
	18 IV 29	18	15—52 N	041—43	1537.9	1536.9	1537.5	—	1533.0	—	1532.6	—	—	1534.0	—	1536.4	1538.2		1541.8		1545.4	1548.6	(1060)																
	19 IV 29	19	13—27 N	042—51	1538.9	1539.0	1539.4	1538.9	1536.1	1533.8																													
Gulf of Aden	24 IV 29	20	12—35 N	045—48	1542.2	—	1534.6	—	1528.6	—	1516.5	—	—	1508.2	1510.6	—	1514.0	—	1512.8	(750)	1513.1	1508.8	(1100)																
Indian Ocean	27 IV 29	21	07—38 N	055—43	1542.5	1542.6	1540.5	—	1532.8	—	1521.2	—	1508.4	—	1501.8	—	1495.1	—		1500.1		1496.2		1495.1	—	1493.9	—	1508.1	—	1523.7	1537.4	(4770)							
	30 IV 29	22	03—48 N	063—48	1541.0	1541.4	1536.2	—	1522.0	—	1510.2	—	1504.1	—	1499.7	—	1495.5	—		1495.4		1493.5		1492.1	—	—	1500.0	—	1516.9	1525.1									
	6 V 29	23	00—05 S	079—45	1540.3	1540.9	1541.4	—	1540.3	—	1524.3	—	1508.9	—	1503.7	—	1499.2	—		1493.7		1492.0		1493.1	—	1495.3	—	1508.1	—	1523.6	1539.4	(4879)							
	10 V 29	24	01—06 S	094—54	1539.9	1540.7	1541.2	—	1542.3	—	1541.9	—	1521.2	—	1509.2	—	1498.9	—		1494.1		1493.2		1491.1	—	1493.9	—	1507.2	—	1522.8	1534.9	(4778)							

MEAN VERTICAL VELOCITIES (V_m's)

Sea	Station	Depth																																														
		200	400	600	800	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200	3400	3600	3800	4000	4200	4400	4600	4800	5000	5200	5400	5600	5800	6000	6200	6400	6600	6800	7000	7200	7400	7600	7800	8000	8200	8400	8600	8800	9000	9200	9400	9600
Eastern part Java sea ...	25-28	(70) 1535																																													
Strait Makasser........	30	1522.0	1506.1	1499.0	1495.1	1492.8	1491.3	1490.5	1490.3	1490.3																																					
	31	1521.2	1506.0	1499.4	1495.3	1492.8	1491.4	1490.8	1490.6	1490.5	1490.6																																				
mean		1522.1	1506.1	1499.2	1495.2	1492.8	1491.4	1490.6	1490.5	1490.4	1490.6																																				
Celebes sea	43	1526.5	1511.2	1502.6	1497.9	1495.0	1493.3	1492.3	1492.0	1491.9	1492.0	1492.5	1493.2	1494.2	1495.1																																
	47	1530.7	1511.1	1502.5	1497.6	1494.6	1493.0	1492.0	1491.6	1491.6	1491.8	1492.3	1492.9	1493.9	1494.9	1495.8	1497.2	1498.5	1499.9	1501.5	1503.0	1504.4	1505.9	1507.3	1508.8	1510.3																					
	57	1530.6	1514.1	1505.1	1499.9	1496.5	1494.5	1493.4	1492.9	1492.7	1492.7	1493.2	1493.8	1494.7	1495.6	1496.5	1497.9	1499.2	1500.5	1502.1	1503.5	1504.8	1506.4	1507.8																							
	77	1527.7	1511.2	1503.5	1499.2	1496.2	1494.3	1493.1	1492.5	1942.3	1942.5	1492.7	1493.4	1494.3	1495.3																																
mean		1528.8	1511.9	1503.4	1498.6	1495.6	1493.8	1492.7	1492.2	1492.1	1492.3	1492.7	1493.3	1494.3	1495.2	1495.1	1497.5	1498.8	1500.2	1501.8	1503.2	1504.6	1506.1	1507.5	1508.8	1510.3																					
Molukken Passage	79	1522.5	1507.7	1500.5	1496.1	1494.4	1493.0	1491.8	1491.0	1490.5	1490.3	1490.5	1490.9	1491.6																																	
	80	1528.9	1513.3	1504.9	1499.8	1496.6	1494.6	1493.2	1492.4	1491.8	1491.5	1491.5	1491.8	1492.4	1493.1	1493.7	1494.9	1496.0	1497.1	1498.5	1499.8	1501.0	1502.5	1503.8																							
mean		1525.7	1510.5	1502.7	1497.9	1495.5	1493.8	1492.5	1491.7	1491.1	1490.9	1491.0	1491.4	1492.0	1493.1	1493.7	1494.9	1496.0	1497.1	1498.5	1499.8	1501.0	1502.5	1503.8																							
Boeroe and Ceram sea	229	1529.3	1516.2	1507.2	1501.6	1498.2	1495.9	1494.4	1493.6	1493.2	1493.0	1493.3	1493.8	1494.5	1495.3	1496.0	1497.3	1498.4	1499.7	1501.1	1502.5	1503.7	1505.2	1506.6	1508.0	1509.4	1511.1																				
	84	1525.7	1511.8	1504.1	1499.3	1496.3	1494.4	1493.4	1493.4																																						
	90	1526.3	1511.6	1503.7	1498.9	1495.9	1493.9	1492.8	1492.2	1492.1																																					
mean		1527.1	1513.2	1505.0	1499.9	1496.8	1494.7	1493.5	1493.1	1492.6	1493.0	1493.3	1493.8	1494.5	1495.3	1496.0	1497.3	1498.4	1499.7	1501.1	1502.5	1503.7	1505.2	1506.6	1508.0	1509.4	1511.1																				
Aroe sea	97	1526.3	1513.8	1505.9	1500.9	1497.7	1495.6	1494.3	1493.8	1493.6	1493.7	1494.1	1494.8																																		
	100	1524.4	1511.5	1503.6	1498.8	1495.9	1494.1	1493.1	1492.6	1492.6	1492.7	1493.3	1494.0	1495.0	1496.0	1496.9	1498.4	1499.8	1501.2																												
	109	1525.5	1511.4	1503.5	1498.8	1495.9	1494.1	1493.0	1492.3																																						
mean		1525.4	1512.2	1504.3	1499.5	1496.5	1494.6	1493.5	1492.9	1493.1	1493.2	1493.7	1494.4	1495.8	1496.0	1496.9	1498.4	1499.8	1501.2																												
Timor sea	118	1527.5	1511.7	1503.4	1498.6	1495.7	1493.9	1492.7	1492.0	1491.6	1491.4	1491.6	1492.2	1492.9	1493.7																																
Savoe sea	135	1525.4	1509.2	1501.6	1497.3	1494.6	1492.8																																								
	142	1524.5	1509.7	1502.0	1497.6	1494.6	1492.6	1491.6	1491.1	1491.0																																					
	155	1522.8	1507.5	1500.6	1496.5	1493.9	1492.2	1490.9	1490.7	1490.6	1490.8	1491.3	1492.0	1493.0	1494.0	1494.9	1496.4																														
mean		1524.2	1508.8	1501.7	1497.1	1494.4	1492.5	1491.2	1490.9	1490.8	1490.8	1491.3	1492.8	1493.0	1494.0	1494.9	1496.4																														
Bali and Flores sea....	173	1522.2	1507.4	1499.9	1495.7	1493.1	1491.4	1490.6	1490.3																																						
	174	1523.1	1508.9	1501.2	1496.9	1494.1	1492.5																																								
	313	1527.5	1509.7	1501.5	1497.1	1494.4																																									
	185	1528.7	1511.5	1503.6																																											
	180	1523.8	1507.8	1500.0	1495.5	1492.9	1491.4	1490.6	1490.3	1490.3	1490.4	1490.9	1491.6	1492.6	1493.5	1494.4	1496.5	1497.2	1498.6	1500.2	1501.7	1503.0	1504.6	1506.0	1507.5	1509.0	1510.9																				
	181	1524.6	1508.1	1500.3	1495.9	1493.3	1491.7	1490.9	1490.5	1490.4	1490.7	1491.1	1491.8	1492.7	1493.7																																
	314	1525.9	1508.7	1500.8	1496.4	1493.7	1492.1	1491.1	1490.7	1490.3																																					
	187	1520.4	1506.8	1499.8	1495.5	1493.1	1491.6	1490.8	1490.5	1490.6	1491.0	1491.7	1492.5	1493.6	1494.7	1495.7	1497.3																														
	191	1532.5	1513.4	1504.3	1499.1	1495.9	1493.9	1492.7	1492.1	1491.9	1491.8																																				
mean		1525.4	1509.1	1501.3	1496.5	1493.8	1492.1	1491.1	1490.7	1490.7	1491.0	1491.2	1492.0	1493.0	1494.0	1495.1	1496.9	1497.2	1498.6	1500.2	1501.7	1503.0	1504.6	1506.0	1507.5	1509.0	1510.9																				
Banda sea	164	1524.9	1510.1	1502.2	1497.5	1494.7	1493.0	1491.9	1491.4	1491.2	1491.3	1491.7	1492.3	1493.0	1493.9	1494.7	1496.1	1497.4	1498.7	1500.2	1501.5																												
	205	1526.4	1511.5	1503.7	1499.0	1496.0	1494.1	1492.8	1492.2	1491.9	1491.9	1492.3	1492.8	1493.6	1494.5	1495.8	1496.5	1497.8	1499.1	1500.6	1502.0																												
	212	1529.3	1512.9	1505.3	1500.1	1496.8	1494.7	1493.4	1492.7	1492.4	1492.4	1492.7	1493.2	1494.0	1494.8	1495.5	1496.9	1498.0	1499.3	1500.8	1502.2	1503.4	1505.0	1506.4	1507.9	1509.2																						
	235	1525.3	1511.5	1503.0	1498.4	1495.5	1493.7	1492.7	1492.1	1491.9	1491.9	1492.2	1492.8	1493.6	1494.5	1495.2	1496.5	1497.6	1498.9	1500.5	1501.9	1503.1	1504.7	1506.1	1507.5	1509.0																						
	253	1526.1	1508.8	1501.3	1499.3	1496.1	1494.1	1492.8	1492.2	1491.9	1491.9	1492.2	1492.8	1493.7	1494.6	1495.3	1496.7	1498.0	1499.2	1500.8	1502.2																												
mean		1526.4	1511.0	1503.1	1498.9	1495.8	1493.9	1492.7	1492.1	1491.9	1491.9	1492.2	1492.8	1493.6	1494.4	1495.2	1496.5	1497.8	1499.0	1500.6	1502.0	1503.2	1504.8	1506.3	1507.7	1509.1																						
Weber deep	321	1521.1	1508.2	1501.8	1497.8	1495.1	1493.4	1492.3	1491.9	1491.7	1491.7	1492.1	1492.7	1493.5	1494.4	1495.1	1496.5	1497.7	1499.0	1500.6	1502.0	1503.2	1504.8	1506.2	1507.6	1509.1	1510.9	1512.5	1514.1	1515.6	1517.3	1518.7	1520.4	1521.9															
	362	1522.3	1510.1	1503.0	1498.3	1495.3	1493.4	1492.3	1491.8	1491.6	1491.6	1491.9	1492.5	1493.3	1494.2	1495.0	1496.4	1497.6	1498.9	1500.5	1501.9	1503.1	1504.7	1506.1	1507.6	1509.0	1510.8	1512.4	1514.0	1515.7	1517.2	1518.7	1520.3	1521.9	1523.5	1525.2	1526.8	1528.4											
	369	1523.6	1510.5	1502.8	1498.1	1495.2	1493.3	1492.2	1491.7	1491.5	1491.4	1491.9	1492.5	1493.3	1494.2	1495.0	1496.4	1497.6	1498.9	1500.5	1501.9	1503.1	1504.7																										
mean		1522.3	1509.6	1502.5	1498.1	1495.2	1493.4	1492.3	1491.8	1491.6	1491.6	1492.0	1492.6	1493.4	1494.3	1495.0	1496.4	1497.6	1498.9	1500.5	1501.9	1503.1	1504.7	1506.1	1507.6	1509.0	1510.9	1512.4	1514.0	1515.6	1517.2	1518.7	1520.3	1521.9	1523.5	1525.2	1526.8	1528.4											
Mean for the Archipelago		1525.6	1510.3	1502.5	1497.9	1495.1	1493.3	1492.3	1491.8	1491.6	1491.7	1492.1	1492.7	1493.5	1494.5	1495.5	1496.7	1497.9	1499.2	1500.6	1502.0	1503.3	1504.8	1506.3	1507.8	1509.3	1510.9	1512.4	1514.0	1515.6	1517.2	1518.7	1520.3	1521.9	1523.5	1525.2	1526.8	1528.4											
Maximum errors in echo distance by using one set of V_m's for the eastern part of the Archipelago		−1 +2	−1 +1	−1 +1	−2 +2	−2 +2	−2 +2	−2 +2	−2 +2	−2 +2	−2 +3	−2 +3	−3 +3	−3 +3	−2 +3	−4 +3	−4 +4	−4 +4	−5 +3	−5 +4	−6 +4	−6 +4	−7 +5	−8 +5	−1 +3	−1 +3	−0 +1	0	0	0	0	0	0	0	0	0	0	0											
Sulu sea	64	1526.8	1514.8	1509.6	1507.0	1506.1	1506.1	1506.7	1507.6	1508.5	1509.5	1510.8	1512.2	1513.6	1515.1	1516.8	1518.2	1519.7	1521.4	1523.0	1524.6	1526.2	1527.9																										
	71	1521.5																																															
Emden deep	262	1530.4	1513.7	1504.0	1498.9	1495.8	1493.8	1492.5	1491.8	1491.4	1491.2	1491.5	1491.8	1492.4	1493.0	1493.8	1494.7	1495.7	1496.9	1498.0	1499.2	1500.5	1501.9	1503.3	1504.1	1506.2	1507.5	1508.9	1510.4	1511.9	1513.5	1515.0	1516.6	1518.2	1519.6	1521.2	1522.9	1524.4	1525.9	1527.7	1529.3	1530.8	1532.5	1534.1	1535.7	1537.3	1538.9	1540.6	15
Indian Ocean	131	1524.1	1511.0	1503.1	1498.7	1495.9	1494.1	1493.0	1492.3	1491.9	1491.8	1491.9	1492.3	1492.8	1493.5																																
	382	1528.6	1512.7	1504.0	1499.4	1496.5	1494.7	1493.5	1492.8	1492.5	1492.4	1492.5	1492.9	1493.4	1494.1	1494.9	1495.6	1496.5	1497.5																												
	145	1522.2	1508.3	1500.8	1496.7	1494.2	1492.8	1492.0	1491.6	1491.4	1491.5	1491.7	1492.1	1492.7	1493.5	1494.3	1495.1	1496.1	1497.1	1498.1	1499.2	1500.1	1501.7	1503.0	1504.2	1505.6	1507.0	1507.6	1509.8	1511.3																		
mean		1525.0	1510.7	1502.6	1498.3	1495.5	1493.9	1492.8	1492.2	1491.9	1491.9	1492.0	1492.4	1493.0	1493.7	1494.6	1495.3	1496.3	1497.3	1498.1	1499.2	1500.4	1501.7	1503.0	1504.2	1505.6	1507.0	1507.6	1509.8	1511.3																		

0	6400	6600	6800	7000	7200	7400	7600	7800	8000	8200	8400	8600	8800	9000	9200	9400	9600	9800	10000
3.7	1520.4	1521.9																	
3.7	1520.3	1521.9	1523.5	1525.2	1526.8	1528.4													
3.7	1520.3	1521.9	1523.5	1525.2	1526.8	1528.4													
.7	1520.3	1521.9	1523.5	1525.2	1526.8	1528.4													
	0	0	0	0	0	0													
5.0	1516.6	1518.2	1519.6	1521.2	1522.9	1524.4	1525.9	1527.7	1529.3	1530.8	1532.5	1534.1	1535.7	1537.3	1538.9	1540.6	1542.2	1543.9	1545.5

APPENDIX No. 2

SIMULTANEOUS SOUNDINGS WITH WIRE, ECHO AND THERMOMETERS

TABLE I

SUMMARY OF OBSERVATIONS

Date 1	Station 2	Reading dial at pulling out 3	Reading dial after reeling in 4	Reeled in according to measuring wheel 5	Wire 6	Correction for measuring wheel and wire thickness 7	Really reeled in 8	Lead 9	Weight instruments (kilos) 10	Tension at pulling out (kilos) 11	Correction for elongation 12	Wire length 13	Inclination of wire 14	Current (nautical 15
13 III '29	A	—	—	2220	1.55	— 4	2216	Sgb.	41	—	— 8	2208	0	—
31 III	11	1083	— 2	1085	”	— 2	1083	”	31	—	— 4	1079	8	—
2 IV	13	2531	—	—	”	— 5	2526	”	31	—	—10	2516	0	—
15 IV	16	1079	—26	1105	”	— 2	1103	”	26	—	— 5	1098	0	—
16 IV	17	515	— 2	517	”	— 1	516	St.	32	—	+ 1	517	5	—
18 IV	18	1062	0	1062	”	— 2	1060	”	40	—	+ 2	1062	15	—
27 IV	21	4775	—15	4770	1.0	— 24	4746	Sgb.	25	—	—13	4733	5	cur
30 IV	22	4077	—10	4087	”	— 20	4067	”	25	—	—10	4057	0	”
6 V	23	4864	—15	4879	”	— 24	4855	St.	32	—	+ 2	4857	13	”
10 V	24a	4760	—18	4778	”	— 24	4754	”	32	—	+ 2	4756	0	”
27 VII	25	61	0	61	1.55	0	61	”	36	—	0	61	0	nil
28 VII	26	81	0	81	”	0	81	”	30	—	0	81	0	—
28 VII	27	61	0	61	”	0	61	Sn.	22	—	0	61	—	—
29 VII	28	70	0	70	”	0	70	”	34	—	0	70	0	—
”	29	689	— 2	691	”	— 2	689	St.	36	—	+ 2	691	0	nil
30 VII	30	1853	— 3	1856	”	— 5	1851	”	36	—	+ 4	1855	0	nil
”	31	2002	— 5	2007	”	— 6	2001	”	36	—	+ 4	2005	0	cur
”	32	—	0	630	”	— 2	628	—	—	—	—	628	0	”
2 VIII	33	2082	— 5	2087	”	— 6	2081	St.	36	—	+ 4	2085	20	?
3 VIII	34	1544	— 2	1546	”	— 5	1541	”	36	—	+ 3	1544	0	cur
”	35	2175	— 4	2179	”	— 6	2173	”	36	—	+ 4	2177	0	2
6 VIII	36	1335	—30	1365	”	— 4	1361	”	36	—	+ 3	1364	20—30	cur
7 VIII	37	55	— 1	56	”	0	56	Sn.	35	—	0	56	0	—
”	38	1378	— 3	1381	”	— 4	1377	St.	41	—	+ 3	1380	0	—
”	39a	2290	— 5	2295	”	— 7	2288	”	36	—	+ 4	2292	0	nil
8 VIII	40	1158	— 1	1159	”	— 3	1156	”	36	—	+ 2	1158	5	—
12 VIII	41	2498	— 6	2504	”	— 7	2497	”	36	—	+ 5	2502	5	—
”	42	698	0	698	”	— .2	696	”	36	—	+ 2	698	0	—
13 VIII	43	2175	— 6	2181	”	— 8	2173	”	36	—	+ 4	2177	5	cur
”	44	—	0	408	1.0	— 2	406	”	—	—	+ 1	407	0	—
18 VIII	45	1012	— 3	1015	”	— 7	1008	”	30	—	0	1008	—	—
”	”	1147	— 2	1149	”	— 8	1141	”	30	—	0	1141	10	—
”	46	2100	— 9	2109	”	— 15	2094	”	36	—	+ 2	2096	0	—
19 VIII	47	5380	+ 51	5329	”	— 37	5292	”	36	—	+ 2	5294	5—10	3—3½
20 VIII	48	5540	—20	5560	”	— 39	5521	”	36	—	+ 2	5523	0	nil
21 VIII	49	3125	—10	3135	”	— 22	3113	”	36	—	+ 2	3115	0	cur
”	50	1798	— 3	1801	”	— 13	1788	”	36	—	+ 2	1790	0	—
”	51	397	0	397	”	— 3	394	Sn.	29	—	0	394	0	nil
23 VIII	52	5039	—19	5058	”	— 35	5023	St.	38	—	+ 2	5025	0	nil
24 VIII	53	5028	—17	5045	”	— 35	5010	”	36	—	+ 2	5012	0	cur
”	54	4010	0	4010	”	— 28	3982	”	36	—	+ 2	3984	0	1/2
25 VIII	55	1109	— 3	1112	”	— 8	1104	”	36	—	0	1104	0	little
3 IX	56	5029	—21	5050	”	— 35	5015	”	36	—	+ 2	5017	0	nil
4 IX	57	4850	—14	4864	”	— 34	4830	”	35	—	+ 2	4832	0	—
5 IX	58	2753	0	2753	”	— 19	2734	”	41	—	+ 2	2736	5	—
”	59	554	0	554	”	— 4	550	Sn.	29	—	0	550	0	cur
5 IX	60	90	0	90	”	0	90	”	22	—	0	90	—	—
5 IX	61	81	0	81	”	0	81	”	22	—	0	81	—	—
6 IX	62	475	0	475	”	— 3	472	St.	42	—	0	472	10	cur
”	63	3081	—14	3095	”	— 22	3073	”	42	90	+ 1	3074	0	—
”	64	4321	—14	4335	”	— 30	4305	”	42	95	+ 2	4307	0	—
7 IX	65	4004	—12	4016	”	— 29	3987	”	41	85	0	3987	0	—
”	66	4512	— 9	4521	”	— 32	4489	Sgb.	37	75	— 2	4487	0	—
”	”	4563	—15	4578	”	— 32	4546	St.	42	100	+ 3	4549	0	—

Bottom	Echo distance		Pression on thermometers (h.g.)	Inversion depth	Stray line	Ther-mome-trical depth	Remarks
	Atlas	Hughes					
16	17	18	19	20	21	22	23
slope	2207	—	—	—	—	—	Gulf of Biscay.
—	1092	1099	—	—	—	—	East of Malta.
—	2550	—	—	—	—	—	Wire broken when reeling in. Eastern part Mediterranean.
—	1083	—	—	—	—	—	Northern part Red Sea.
—	499	507	—	—	—	—	Midlle part Red Sea.
—	1082	—	—	—	—	—	Southern part Red Sea.
flat	4645	—	—	—	—	—	N.W. part Indian Ocean.
"	4007	—	—	—	—	—	West of Maladives.
"	4706	—	—	—	—	—	East of Maladives.
"	4692	—	—	—	—	—	West of Sumatra.
"	60	—	—	—	—	—	
—	76	—	—	76	5	—	
—	56	—	—	56	5	—	
"	75	—	—	—	—	—	
"	694	—	—	—	—	—	good opportunity.
"	1806	—	—	—	—	—	" "
"	1917	—	—	—	—	—	
rugged	635	—	—	—	—	—	
flat	1967	—	—	—	—	—	
slope	1506	—	—	—	—	—	
flat	2038	—	—	—	—	—	
slope	1151	—	—	—	—	—	
"	55	—	—	—	—	—	
"	1426	—	—	—	—	—	
flat	2199	—	—	—	—	—	good opportunity.
slope	1163	—	—	—	—	—	
flat	2408	—	—	—	—	—	
slope	682	—	—	—	—	—	
"	2114	—	—	—	—	—	
flat	418	—	—	—	—	—	
slope	983	—	—	—	—	—	
"	1025 1123	—	—	—	—	—	
"	2027	—	—	—	—	—	
"	5167	—	—	—	—	—	wire rubbed against hull.
flat	5488	—	—	—	—	—	good opportunity.
"	3045	—	—	—	—	—	
slope	1748	—	—	—	—	—	
flat	419	—	—	—	—	—	good opportunity.
"	5034	—	—	—	—	—	" "
"	5034	—	—	—	—	—	
slope	3952	—	—	—	—	—	
"	1018	—	—	—	—	—	
flat	5063	—	—	—	—	—	" "
rugged	4686	—	—	—	—	—	
slope	2728	—	—	—	—	—	
rugged	587	—	—	—	—	—	
—	97	—	—	85	5	—	
—	86	—	—	76	5	—	
slope	468	—	—	—	—	—	Sulu sea.
"	3059	—	—	—	—	—	
flat	4378	—	—	—	—	—	
"	3946	—	—	—	—	—	
—	4478	—	—	—	—	—	
—	4613	—	—	—	—	—	

Date	Station	Reading dial at pulling out	Reading dial after reeling in	Reeled in according to measuring wheel	Wire	Correction for measuring wheel and wire thickness	Really reeled in	Lead	Weight instruments (kilos)	Tension at pulling out (kilos)	Correction for elongation	Wire length	Inclination of wire	Current (nautical
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
27 X '29	120	2115	— 17	2132	1.55	— 17	2115	St.	38	105	+ 5	2120	15	cur
〃	121	2276	— 8	2284	〃	— 18	2266	〃	38	100	+ 4	2270	5	〃
28 X	122	1172	— 2	1174	〃	— 9	1165	〃	38	80	+ 1	1166	0	little
〃	123	500	0	500	〃	— 4	496	Sn.	34	—	— 2	494	0	〃
〃	124_1	399	0	399	〃	— 4	395	St.	38	75	0	395	0	little
29 X	125	2630	— 9	2639	〃	— 24	2615	〃	38	95	+ 2	2617	0	¾
〃	126	433	0	433	〃	— 4	429	Sn.	34	—	— 2	427	10	½
〃	127	2310	— 8	2318	〃	— 21	2297	St.	42	105	+ 6	2303	5	½
30 X	128	1455	— 4	1459	〃	— 13	1446	〃	38	105	+ 4	1450	0	—
〃	129	441	0	441	〃	— 4	437	〃	38	105	+ 1	438	5	—
8 XI	130	1945	— 5	1950	〃	— 20	1930	〃	38	80	+ 1	1931	0	1
〃	131	2941	— 10	2951	〃	— 30	2921	〃	38	110	+ 6	2927	0	½
10 XI	132	1332	0	1332	〃	— 13	1319	〃	38	125	+ 6	1325	0	—
13 XI	133	573	0	573	〃	— 6	567	Sn.	38	—	— 2	565	0	little
〃	134	961	— 2	963	〃	— 10	953	〃	36	—	— 3	950	5	2
〃	135	1165	— 4	1169	〃	— 13	1156	〃	36	—	— 3	1153	8	1
〃	136	381	— 2	383	〃	— 4	379	〃	36	—	— 2	377	5	cur
16 XI	137	489	0	489	〃	— 5	484	〃	34	—	— 2	482	—	〃
〃	138	968	— 1	969	〃	— 10	959	〃	34	—	— 3	956	10	nil
〃	139	424	0	424	〃	— 5	419	〃	34	—	— 2	417	5	2
17 XI	140	1090	?	1090	〃	— 12	1078	〃	34	—	— 3	1075	3	cur
〃	141	1503	— 3	1506	〃	— 18	1488	St.	38	95	+ 3	1491	5	—
21 XI	142	1837	— 4	1841	〃	— 22	1819	〃	41	115	+ 6	1825	—	—
22 XI	143	1685	— 4	1689	〃	— 22	1667	〃	42	95	+ 3	1670	15	—
24 XI	144	2811	— 9	2820	1.0	— 45	2775	〃	38	125	+ 2	2777	0	—
〃	145	5787	— 20	5807	〃	— 93	5714	Sgb.	35	—	— 16	5698	0	—
25 XI	146	5450	— 8	5458	〃	— 86	5372	〃	46	95	0	5372	0	cur
27 XI	147	3720	+ 11	3709	〃	— 59	3650	St.	41	115	+ 5	3655	0	〃
〃	148	1215	0	1215	〃	— 19	1196	〃	41	—	0	1196	0	〃
7 XII	149	1388	0	1388	〃	— 22	1366	〃	38	75	0	1366	0	—
〃	150	206	0	206	〃	— 3	203	Sn.	34	—	0	203	0	—
〃	151	958	0	958	〃	— 15	943	〃	34	—	— 3	940	20	—
8 XII	152	2003	— 6	2009	〃	— 32	1977	St.	38	95	+ 2	1979	5	—
〃	153	2988	— 6	2994	〃	— 48	2946	〃	38	120	+ 5	2951	8	—
9 XII	154	1995	— 6	2001	〃	— 32	1969	〃	38	—	+ 2	1971	5	nil
〃	155	3379	— 6	3385	〃	— 54	3331	〃	38	—	+ 2	3333	—	cur
12 XII	156	1912	— 7	1919	〃	— 30	1889	〃	38	70	0	1889	10	—
〃	〃	1880	— 7	1887	〃	— 30	1857	Sn.	34	—	— 5	1852	0	—
13 XII	157	410	0	410	〃	— 6	404	〃	34	—	0	404	10	—
〃	158	2015	— 5	2020	〃	— 32	1988	St.	40	85	+ 1	1989	10	cur
〃	159	3270	— 10	3280	〃	— 53	3227	〃	38	75	0	3227	0	〃
〃	160	3270	— 10	3280	〃	— 53	3227	〃	40	80	0	3227	5	〃
16 XII	161	999	— 2	1001	〃	— 16	985	Sn.	34	—	— 3	982	10	—
〃	162	2050	— 8	2058	〃	— 33	2025	St.	38	±60	0	2025	10	little
17 XII	163	3430	— 13	3443	〃	— 54	3389	〃	42	80	0	3389	10	cur
〃	164	3940	— 20	3960	〃	— 63	3897	St.	40	± 60	0	3897	5	1
21 XII	165	442	— 1	443	〃	— 6	437	〃	38	—	0	437	0	—
〃	166	2032	— 5	2037	〃	— 35	2002	〃	40	90	+ 2	2004	0	—
22 XII	167	3480	— 11	3491	〃	— 56	3435	〃	36	95	+ 2	3437	0	1
〃	168	2677	— 7	2684	〃	— 43	2641	〃	38	—	+ 2	2643	0	½
〃	169	670	— 2	672	〃	— 11	661	〃	34	—	0	661	0	—
23 XII	170	1402	— 3	1405	〃	— 22	1383	Sn.	34	—	— 3	1380	10	—
29 I '30	171	87	0	87	〃	0	87	St.	35	—	0	87	—	—
30 I	172	715	—	—	〃	— 11	704	〃	38	80	+ 1	705	15	—
〃	〃	736	— 1	737	〃	— 11	726	〃	38	75	0	726	5	—

Bottom	Echo distance		Pression on thermometers (h.g.)	Inversion depth	Stray line	Thermometrical depth	Remarks
	Atlas	Hughes					
16	17	18	19	20	21	22	23
—	2016	—	—	—	—	—	
slope	2299	—	—	—	—	—	
"	1149	—	—	—	—	—	
rugged	442	—	—	—	—	—	
—	374	—	—	—	—	—	
flat	2616	—	—	—	—	—	
slope	378	—	—	—	—	—	
—	2362	—	—	—	—	—	
flat	1470	—	—	—	—	—	
slope	388	—	—	—	—	—	
—	1886	—	1853	1795	31	1826	current layer ± 400 m.
—	2935	—	2963	2870	31	2901	Ind. Ocean off Soemba-Roti.
flat	1334	—	1314	1272	31	1303	
rugged	503	—	—	—	—	—	
flat	1021	—	932	908	31	939	
"	1197	—	1156	1124	31	1155	
rugged	388	—	—	—	—	—	Ind. Ocean off Roti.
slope	432	—	419	409	31	440	
flat	963	—	941	915	31	946	
slope	424	—	—	—	—	—	
flat	1084	—	1070	1040	31	1071	
slope	1547	—	—	—	—	—	
"	1934	—	1844	1790	31	1821	
"	1620	—	1656	1610	31	1641	
"	2849	—	—	—	—	—	
rugged	5979 5799	—	5842	5631	91	5722	Ind. Ocean off Soemba.
flat	5339	—	5541	5340	31	5371	
slope	3698	—	3773	3644	31	3675	
flat	1240	—	1208	1170	31	1201	
slopes	1407	—	1376	1332	31	1363	
"	223	—	—	—	—	—	
—	943	—	888	865	31	896	
—	1991	—	1943	1887	31	1918	good opportunity.
—	3000	—	2991	2897	31	2928	" "
flat	2147	—	2003	1945	31	1976	
"	3400	—	3376	3267	31	3298	
"	1879	—	1880	1825	31	1856	
"	1859	—	—	—	—	—	
slope	451	—	418	407	31	438	
"	1975	—	1990	1932	31	1963	
flat	3229	—	3327	3219	31	3250	
"	3209	—	3297	3190	31	3221	
rugged	1073	—	977	948	31	979	
flat	2105	—	2037	1977	31	2008	wire sounding not reliable.
—	3348	—	3311	3205	91	3296	thermometrical sounding perhaps not accurate.
flat	3812	—	3933	3803	31	3834	
slope	417	—	414	404	31	435	
"	2051	—	2030	1971	31	2002	
flat	3580	—	3531	3417	31	3448	
"	2594	—	—	—	—	—	wire broken.
steep	586	—	—	—	—	—	
—	1431	—	1367	1330	31	1361	
—	—	—	—	82	5	—	
—	730	—	—	—	—	—	
—	774	—	—	—	—	—	

Date	Station	Reading dial at pulling out	Reading dial after reeling in	Reeled in according to measuring wheel	Wire	Correction for measuring wheel and wire thickness	Really reeled in	Lead	Weight instruments (kilos)	Tension at pulling out (kilos)	Correction for elongation	Wire length	Inclination of wire	Current (nautical
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
22 III '30	220	2650	— 7	2657	1.0	— 43	2614	Sn.	34	—	— 7	2607	10	1
"	221	3697	—18	3715	"	— 59	3656	St.	38	—	+ 2	3658	0	—
"	222	1255	— 4	1259	"	— 20	1239	Sn.	37	—	— 3	1236	10	—
23 III	223	505	— 1	506	"	— 8	498	"	37	—	— 1	497	5	—
24 III	224	1140	— 7	1147	"	— 18	1129	"	37	—	— 3	1126	15	¼
"	225	1985	—10	1995	"	— 32	1963	"	37	—	— 6	1957	15-25	—
"	226	438	0	438	"	— 6	432	"	37	—	0	432	0	—
"	227	3001	—11	3012	"	— 50	2962	St.	44	100	+ 2	2964	5	—
3 IV	test	—	—	—	"	—	—	lead	12	—	—	490	0	1
"	"	—	—	—	"	—	—	"	12	—	—	490	0	1
4 IV	228	2708	—10	2718	"	— 43	2675	St.	38	no max	0	2675	0	—
5 IV	229	5190	—21	5211	"	— 83	5128	"	44	125	+ 7	5135	0	—
"	230	1445	— 4	1449	"	— 22	1427	Sn.	34	—	— 4	1423	10	—
6 IV	231	1123	— 4	1127	"	— 17	1110	"	34	—	— 3	1107	5	½
7 IV	232	4637	—18	4655	"	— 74	4581	St.	44	125	+ 7	4588	5	—
"	233	1827	— 7	1834	"	— 29	1805	"	38	75	0	1805	0	—
8 IV	234	3755	—17	3772	"	— 60	3712	"	41	no max	0	3712	0	—
"	235	5094	—23	5117	"	— 82	5035	"	41	105	+ 2	5037	0	—
9 IV	236	3652	—14	3666	"	— 58	3608	"	45	145	+ 10	3618	0	—
"	237	3203	—10	3213	"	— 51	3162	"	—	105	+ 3	3165	0	—
11 IV	239	1300	— 5	1305	"	— 20	1285	Sn.	37	—	— 3	1282	30	—
"	240	3187	—	—	"	— 51	3136	St.	44	145	+ 8	3144	0	—
12 IV	241	4902	—25	4927	"	— 78	4849	"	41	115	+ 4	4853	10	—
"	242	3400	—15	3415	"	— 54	3361	"	41	95	+ 2	3363	10	—
13 IV	243	1242	— 5	1247	"	— 19	1228	Sn.	34	—	— 3	1225	0	—
14 IV	244	2605	— 7	2612	"	— 41	2571	St.	33	75	0	2571	0	½
"	245	4485	—16	4501	"	— 72	4429	"	33	85	0	4429	0	1
15 IV	246	4441	—15	4456	"	— 72	4384	"	30	85	0	4384	10	1
"	247	1545	— 5	1550	"	— 25	1525	Sn.	30	—	— 4	1521	0	2
16 IV	248	2698	—10	2708	"	— 43	2665	St.	38	105	+ 3	2668	10	1½
17 IV	249	4160	—18	4178	"	— 67	4111	"	41	95	+ 1	4112	10	½
"	250	1053	— 2	1055	"	— 16	1039	Sn.	34	—	— 3	1036	5	—
"	251	5146	—20	5166	"	— 82	5084	St.	38	95	0	5084	0	—
18 IV	252	1590	— 5	1595	"	— 26	1569	Sn.	34	—	— 4	1565	15	—
"	253	4081	—15	4096	"	— 66	4030	Sgb.	40	—	—10	4020	0	½
8 V	253_1	960	— 7	967	"	— 16	951	Sn.	28	—	— 2	949	10	¼
9 V	255	3273	—10	3283	"	— 53	3230	St.	38	75	0	3230	5	—
10 V	256	1232	— 4	1236	"	— 19	1217	Sn.	34	—	— 3	1214	10	1¼
"	257	3019	—11	3030	"	— 48	2982	St.	38	—	+ 2	2884	5	—
13 V	260	7940	—30	7970	"	—128	7842	Sgb.	60	70	0	7842	5	—
15 V	261_1	10005	—38	10043	"	—160	9883	"	60	75	0	9883	0	—
16 V	262	10220	—37	10257	"	—160	10097	"	60	85	0	10097	10-20	—
17 V	263	3822	—14	3836	"	— 61	3775	St.	32	—	0	3775	20	—
18 V	264	9295	—47	9342	"	—149	9193	Sgb.	60	—	0	9193	5	2
"	265	5060	—17	5077	"	— 82	4995	"	42	85	0	4995	10	—
19 V	266	2696	—10	2706	"	— 43	2663	St.	42	90	+ 1	2664	15	2
"	267	427	0	427	"	— 6	421	Sn.	38	—	— 1	420	5	1¼
"	268	807	0	807	"	— 13	794	"	38	—	— 2	792	5	3
22 V	269	595	— 1	596	"	— 9	587	"	38	—	— 1	586	10	2
"	270	4780	—20	4800	"	— 77	4723	St.	42	no max	0	4723	5	—
23 V	271	7950	—30	7980	"	—128	7852	Sgb.	46	—	+ 8	7860	0	—
"	272	5410	—20?	—	"	— 86	5324	St.	42	95	0	5324	5	—
25 V	275	5595	—22	5617	"	— 90	5527	"	42	80	0	5527	5	¼

Bottom	Echo distance		Pression on thermometers (h.g.)	Inversion depth	Stray line	Thermometrical depth	Remarks
	Atlas	Hughes					
16	17	18	19	20	21	22	23
—	2620	—	—	—	—	—	
flat	3704	—	3738	3616	33	3649	
rugged	1164	—	—	—	—	—	
"	499	—	—	—	—	—	
—	1072	—	1082	1052	33	1085	
—	1929	—	—	—	—	—	
slope	533	—	296	288	33	321	th. depth wrong.
—	2959	—	3029	2934	33	2967	
flat	469	490	—	—	—	—	mean of $\frac{80}{59}$ 32 observations.
"	470		—	—	—	—	
slope	2644	—	2640	2557	33	2590	
rugged	5146	—	5290	5100	33	5133	
flat	1402	—	1407	1369	33	1402	
slope	1168	—	1092	1061	33	1094	
flat	4653	—	4727	4563	33	4596	
"	1768	—	1779	1728	33	1761	good opportunity.
—	3532	—	—	—	—	—	
flat	5056	—	—	—	—	—	
slope	3506	—	3692	3564	33	3597	
"	3159	—	3237	3135	33	3168	
steep	1164	—	1242	1203	33	1236	
slope	3330	—	—	—	—	—	wire broken.
flat	4841	—	—	—	—	—	
—	3358	—	—	—	—	—	
steep	1164	—	—	—	—	—	
"	2588	—	—	—	—	—	
flat	4486	—	—	—	—	—	
"	4387	—	—	—	—	—	
steep	1531	—	—	—	—	—	
slope	2663	—	—	—	—	—	
—	4182	—	—	—	—	—	strong current at ± 800 m depth.
slope	1048	—	—	—	—	—	
flat	5145	—	—	—	—	—	
steep	1449	—	—	—	—	—	
slope	4048	—	—	—	—	—	
"	945	—	—	—	—	—	
flat	3348	—	—	—	—	—	
"	1240	—	—	—	—	—	
—	2989	—	—	—	—	—	
rugged	8078	—	—	—	—	—	no max at pulling out
—	9806	—	—	—	—	—	id.
—	10029	—	—	—	—	—	series observations 11 echo-leadsmen id.
—	—	—	—	3722	33	—	
flat	9394	—	—	—	—	—	current layer 200—300 m id.
slope	4921	—	—	—	—	—	
steep	2417	—	—	—	—	—	current layer 100—200 m.
slope	427	—	—	—	—	—	
"	750	—	—	—	—	—	Pacific.
—	529	—	—	—	—	—	
slope	4525	—	—	—	—	—	
"	8037	—	—	—	—	—	
—	5313	—	—	—	—	—	
slope	5616	—	—	—	—	—	wire broken no max. at pulling out

Date	Station	Reading dial at pulling out	Reading dial after reeling in	Reeled in according to measuring wheel	Wire	Correction for measuring wheel and wire thickness	Really reeled in	Lead	Weight instruments (kilos)	Tension at pulling out (kilos)	Correction for elongation	Wire length	Inclination of wire	Current (nautical
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
26 V '30	276	4374	— 15	4389	1.0	— 70	4319	St.	42	100	+ 2	4321	10	—
27 V	277	608	— 1	609	"	— 9	600	Sn.	34	—	— 1	599	0	—
"	278	488	0	488	"	— 8	480	St.	42	95	+ 1	481	0	—
"	"	500	0	500	4.0	— 3	497	*St.*	134	500	—	497	0	—
"	279_1	502	0	502	"	— 3	499	"	120	450	—	499	0	nil
"	280	385	0	385	1.0	— 4	381	St.	46	100	+ 1	382	5	"
"	280_1	365	0	365	4.0	— 2	363	*St.*	110	450	—	363	0	"
30 V	283	582	— 1	583	1.0	— 8	575	Sn.	34	—	— 1	574	0	—
"	284	3737	— 12	3749	"	— 59	3690	St.	42	100	+ 3	3693	0	½—1
31 V	285	2110	— 7	2117	"	— 34	2083	"	36	60	— 1	2082	20	—
"	286	652	— 2	654	"	— 10	644	Sn.	34	—	— 1	643	10-15	—
1 VI	287	712	— 2	714	"	— 11	703	"	34	—	— 2	701	0	1¼
"	288	2249	— 7	2256	"	— 36	2220	St.	42	—	+ 2	2222	0	½
12 VI	289	1609	— 6	1615	"	— 26	1589	Sn.	34	—	— 4	1585	10	—
13 VI	290	1168	— 6	1174	"	— 19	1155	"	34	—	— 3	1152	5	—
"	291	2667	— 10	2677	"	— 43	2634	St.	42	85	+ 2	2636	10	—
"	292	2535	— 9	2544	"	— 41	2503	"	42	85	+ 2	2505	15	2
16 VI	293	866	— 1	867	"	— 14	853	Sn.	34	—	— 2	851	0	—
"	294	1928	— 8	1936	"	— 31	1905	"	34	—	— 5	1900	5	1
"	295	950	— 2	952	"	— 15	937	"	34	—	— 2	935	8	½
18 VI	296	3622	— 16	3638	"	— 57	3581	St.	41	105	+ 3	3584	15-20	2
"	297	2751	— 11	2762	"	— 44	2718	"	43	no max	0	2718	0	2
19 VI	298	842	— 2	844	"	— 13	831	Sn.	36	—	— 2	829	0	—
"	299	1605	— 7	1612	"	— 26	1586	"	36	—	— 4	1582	5	2
"	"	1414	— 5	1419	"	— 22	1397	"	36	—	— 3	1394	7	—
"	300	729	— 3	732	"	— 11	721	"	36	—	— 2	719	7	—
23 VI	301	5243	— 25	5268	"	— 85	5183	St.	43	110	+ 3	5186	5	¼
24 VI	303	4574	— 20	4594	"	— 74	4520	"	40	85	0	4520	5	1/8
25 VI	305	3621	— 15	3636	"	— 57	3579	"	40	95	+ 1	3580	0	nil
4 VII	309_1	5205	— 25	5230	"	— 83	5147	Sgb.	37	85	0	5147	10	—
31 VIII	320	2619	— 10	2629	"	— 42	2587	St.	44	105	+ 4	2591	10	little
3 IX	321	6714	— 30	6744	"	— 107	6637	"	34	no max	0	6637	5	¼
"	322	3375	— 14	3389	"	— 54	3335	"	40	100	+ 2	3337	5	little
"	323	510	0	510	"	— 8	502	Sn.	36	—	— 1	501	0	"
4 IX	324	2180	— 7	2187	"	— 35	2152	St.	40	65	0	2152	0	cur
6 IX	325	2038	— 8	2046	"	— 32	2014	"	40	75	0	2014	10	—
7 IX	326	498	— 2	500	"	— 8	492	Sn.	30	—	— 1	491	10	—
"	327	1471	— 5	1476	"	— 24	1452	St.	44	95	+ 1	1453	10	—
"	328	2995	— 13	3008	"	— 48	2960	"	40	80	0	2960	5	¼
8 IX	330	4469	—	4469	4.0	— 27	4442	*St.*	153	650	+ 4	4446	5	—
19 IX	331	5040	—	5040	"	— 30	5010	"	153	675	—	5010	0	—
21 IX	333	2756	— 10	2766	1.0	— 44	2722	St.	40	75	0	2722	10	1½
22 IX	334	2703	— 10	2713	"	— 44	2669	"	40	100	+ 3	2672	0	—
23 IX	335	2162	— 9	2171	"	— 35	2136	"	40	130	+ 7	2143	0	¼
"	336	2409	— 9	2418	"	— 38	2380	"	40	100	+ 3	2383	0	little
"	337	3925	— 17	3942	"	— 62	3880	"	44	no max	0	3880	10	1
"	338	1810	— 6	1816	"	— 29	1787	"	44	95	+ 2	1789	5	cur
"	339	550	— 2	552	"	— 8	544	Sn.	38	—	— 1	543	15	strong
24 IX	340	2550	— 11	2561	"	— 41	2520	St.	40	no max	0	2520	10	1
26 IX	341	—	—	—	4.0	—	—	lead	—	—	—	—	—	—
27 IX	343	1220	— 4	1224	1.0	— 19	1205	St.	40	no max	0	1205	10	1
"	344	2530	— 11	2541	"	— 40	2501	"	40	100	+ 3	2504	10	1

Bottom	Echo distance		Pression on thermometers (h.g.)	Inversion depth	Stray line	Thermometrical depth	Remarks
	Atlas	Hughes					
16	17	18	19	20	21	22	23
flat	4313	—	—	—	—	—	Pacific.
—	577	—	—	—	—	—	
—	510	—	—	—	—	—	
—	529	—	—	—	—	—	
—	504	—	—	—	—	—	Kaoe-bay.
—	379	—	—	—	—	—	
—	355	—	—	—	—	—	
—	597	—	—	—	—	—	
flat	3698	—	—	—	—	—	
"	2006	—	1973	1916	33	1949	
steep	659	—	534	522	33	555	
rugged	731	—	651	635	33	668	
—	2279	—	2232	2168	33	2201	
—	1582	—	—	—	—	—	
—	1164	—	—	—	—	—	
slope	2562	—	2562	2484	33	2517	
"	2529	—	2483	2410	33	2443	
"	808	—	837	814	33	847	
—	1938	—	1845	1792	33	1825	current layer 300 m.
—	904	—	799	775	33	808	th. depth wrong.
—	3438	—	3397	3289	33	3322	
—	2624	—	2587	2508	33	2541	
slope	851	—	796	773	33	806	
—	1501	—	1505	1462	33	1495	
—	1412	—	—	—	—	—	
—	654	—	648	632	33	665	
flat	5164	—	3250	3151	33	3184	th. depth wrong.
"	4455	—	4545	4386	33	4419	
"	3558	—	3592	3474	33	3507	good opportunity.
—	5096	—	5215	5015	93	5108	
steep	2571	—	2611	2531	33	2564	
flat	6606	—	6648	6393	33	6426	th. depth wrong.
slope	3420	—	3391	3281	33	3314	
rugged	567	—	418	408	33	441	th. depth wrong
—	2230	—	2169	2106	33	2139	
—	2087	—	2025	1963	33	1996	
slope	475	—	453	441	33	474	
—	1450	—	1454	1412	33	1445	good opportunity.
—	2942	—	3004	2909	33	2942	" "
—	4492	—	4550	4390	60	4450	when starting reeling in tension 500
flat	5147	—	4900	4726	300	5026	" " " " " 550
slope	2743	—	2745	2661	33	2694	
—	2718	—	2706	2625	33	2658	
—	2096	—	—	—	—	—	
—	2349	—	2415	2345	33	2378	
slope	3855	—	1368	1300	33	1333	th. depth wrong.
steep	1842	—	—	—	—	—	
—	471	—	374	365	33	398	
—	2549	—	2552	2477	33	2510	
—	—	—	—	1205 1285	100 20	1305 —	
rugged	1309	—	—	—	—	—	
flat	2524	—	2522	2446	33	2479	

Date	Station	Reading dial at pulling out	Reading dial after reeling in	Reeled in according to measuring wheel	Wire	Correction for measuring wheel and wire thickness	Really reeled in	Lead	Weight instruments (kilos)	Tension at pulling out (kilos)	Correction for elongation	Wire length	Inclination of wire	Current (nautical
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
27 IX '30	345	2820	— 13	2833	1.0	— 45	2788	St.	44	no max	0	2788	10	—
„	346	508	— 1	509	„	— 8	501	Sn.	36	—	— 1	500	5	—
28 IX	347	3080	0	3080	4.0	— 18	3062	*St.*	152	650	—	3062	5	—
1 X	348_1	2218	—	—	„	—	—	lead	—	—	—	2218	—	—
3 X	350	2623	— 11	2634	1.0	— 42	2592	St.	44	95	+ 2	2594	0	½
„	351	800	— 2	802	„	— 13	789	Sn.	36	—	— 2	787	10	—
„	352	1060	— 5	1065	„	— 17	1048	St.	40	no max	0	1048	10	cur
4 X	353	1900	— 7	1907	„	— 30	1877	„	44	90	+ 2	1879	5	„
6 X	354	600	— 2	602	„	— 10	592	Sn.	36	—	— 1	591	5	—
„	354a	1380	— 6	1386	„	— 22	1364	St.	44	no max	0	1364	0	little
8 X	355	2070	— 9	2079	„	— 33	2046	„	44	no max	0	2046	0	—
11 X	357	1600	— 8	1608	„	— 26	1582	„	44	„	0	1582	0	—
„	358	4490	0	4490	4.0	— 27	4463	*St.*	176	625	—	4463	0	—
„	359	3595	— 15	3610	1.0	— 58	3552	St.	44	no max	0	3552	5	¼
12 X	360	1118	— 5	1123	„	— 18	1105	Sn.	36	—	— 3	1102	5	1½
„	361	2655	— 12	2667	„	— 43	2624	St.	44	100	+ 3	2627	0	—
22 X	362	7433	— 33	7466	„	— 120	7346	Sgb,	60	100	0	7346	10	—
23 X	363	940	— 4	944	„	— 14	930	St.	44	no max	0	930	0	—
„	364	1090	— 4	1094	„	— 17	1077	„	40	„	0	1077	15	cur
„	„	1170	— 5	1175	„	— 19	1156	Sn.	28	—	— 3	1153	0	1
24 X	364_b	4468	— 10	4478	4.0	— 27	4451	*St.*	160	—	—	4451	6	—
25 X	365	6402	— 26	6428	1.0	— 102	6326	Sgb.	34	70	— 15	6311	0	little
26 X	368	2485	— 9	2494	„	— 40	2454	St.	44	100	+ 4	2458	0	nil
27 X	369	4523	— 23	4546	„	— 72	4474	„	44	100	+ 3	4477	5	„
28 X	370	1722	— 8	1730	„	— 27	1703	„	40	80	+ 1	1704	0	little
29 X	372	1000	— 4	1004	„	— 16	988	Sn.	38	—	0	988	5	cur
30 X	373	4120	— 24	4144	„	— 66	4078	St.	44	100	+ 2	4080	10	—
1 XI	374	2535	— 5	2540	4.0	— 15	2525	*St.*	180	650	—	2520	5	—
„	375	1450	— 5	1455	1.0	— 23	1432	St.	44	no max	0	1432	5	nil
2 XI	376	3345	— 16	3361	„	— 53	3308	„	40	105	+ 4	3312	0	cur
3 XI	377	3415	— 15	3430	„	— 54	3376	„	44	95	+ 3	3379	5	„
4 XI	379	3338	— 8	3346	4.0	— 20	3326	*St.*	160	600	—	3318	0	nil
„	380	3357	— 15	3372	1.0	— 54	3318	St.	40	85	0	3318	0	little
5 XI	381	1070	— 5	1075	„	— 18	1057	Sn.	36	—	— 3	1054	15	cur
11 XI	382	3520	— 9	3529	4.0	— 20	3509	*St.*	172	650	— 9	3500	5	½
trial trip	—	—	—	—	—	—	—	—	—	—	—	—	—	—
14 III '29	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Bottom	Echo distance		Pression on thermometers (h.g.)	Inversion depth	Stray line	Thermometrical depth	Remarks
	Atlas	Hughes					
16	17	18	19	20	21	22	23
slope	2703	—	2790	2703	33	2736	
steep	442	—	470	459	33	492	
—	3065	—	2850	2761	300	3061	
—	2233	—	2135	2073	125	2198	with mach. ser. obs. } Pacific.
—	2623	—	2600	2525	33	2558	
slope	756	—	776	755	33	788	
steep	1045	—	1014	985	33	1018	
flat	1939	—	1894	1839	33	1872	
slope	553	—	560	546	33	579	
"	1354	—	1372	1332	33	1365	
"	2009	—	2076	2016	33	2049	
steep	1600	—	1590	1546	33	1579	
flat	4465	—	4055	3917	550	4467	
"	3576	—	3634	3516	33	3549	
steep	1050	—	1142	1109	33	1142	th. depth presumable wrong.
—	2632	—	2679	2596	33	2629	
flat	7349	—	—	—	—	—	
slope	985	—	888	865	33	898	
—	1106	—	1067	1038	33	1071	
—	1185	—	—	—	—	—	
—	4470	—	—	4395	40	4435	
flat	6377	—	6531	6280	33	6313	
flat	2498	—	2492	2418	33	2451	
"	4545	—	4593	4435	33	4468	
"	1744	—	1701	1652	33	1685	
slope	956	—	933	907	33	940	
flat	4120	—	2736	2660	33	2693	th. depth wrong.
slope	2645	—	2534	2459	50	2509	
—	1479	—	1428	1389	33	1422	
flat	3343	—	3369	3259	33	3292	
"	3418	—	3427	3314	33	3347	
"	3321	—	—	—	—	—	
"	3361	—	—	—	—	—	good opportunity.
slope	1030	—	1014	983	33	1016	
"	3517	—	3091	2992	500	3492	Ind. Ocean S of Soemba.
—	1160	1172	—	—	—	—	Gulf of Biscay.
—	400	390	—	—	—	—	" " "

TABLE II

Comparisions between Wire- and Atlasdepths, if good opportunity for comparision, arranged according to depth.

Station	Wire-depth	Wire-Atlas +	Wire-Atlas —	mean	Station	Wire-depth	Wire-Atlas +	Wire-Atlas —	mean
280*	363×	8		300 m, + 2	152*	[1]1979		12	
280*	382	3			348$_1$*	2218×		15	2250 m, —11
51	[1]394		25		39$_2$	[1]2292+	93		
107	[1]395+		28		336	2383	34		
124$_1$	[1]395+	21		400 m, 0	368	2458		40	
44	[1]407		11		13	[1]2516+		34	
278*	481		29		361	2627		5	
test	490	21			79	[1]2627		69	
test	490	20			77	[1]2803		35	
278*	497×		32		118	[1]2925+	47		
279$_1$*	499×		5	500 m, — 1	153	[1]2951		49	
111	[1]563+	25			328	2960	18		
98	[1]568+	10			227	[1]2964	5		
283	574		23		347	3062×		3	
108	[1]580+	8			379	3318×		3	3250 m, —12
277*	599	22		600 m, — 4	380	3318		43	
85	[1]684	1			359	3552		24	
92	[1]691+	61			305	3580	22		
29	[1]691+		3		221	[1]3658		46	
172	[1]705		25	700 m, — 4	65*	[1]3987	41		4000 m, —13
106	[1]723+		85	800 m, — 5	64*	[1]4307		71	
105	[1]937+		8	900 m, — 7	218	[1]4398		26	
138	[1]956+		7		358	4463×		2	
16*	[1]1098+	15		1000 m, — 7	369	4477		68	
132*	[1]1325+		9	1100 m, — 8	66*	[1]4487	9		4500 m, —14
89	[1]1422		30	1200 m, — 9	303	4520	65		
375	1432		47	1300 m, — 9	66*	[1]4549		64	
128	[1]1450+		20	1400 m, — 9	80	[1]4626	80		
327	1453	3		1500 m. — 9	75	[1]4786		72	
109	[1]1513+		12		210	[1]4919	13		
84	[1]1532		55	1600 m, — 9	331	5010×		(137)	
112	[1]1543+	33			56	[1]5017		46	
370	1704		40	1700 m, —10	52	[1]5025		9	
233	1805	37			235	5037		19	
156	[1]1852		7	1800 m, —10	251	5084		61	
30	[1]1855+	49			48	[1]5523	35		5500 m, —15
154	[1]1971		(176)	1900 m, —10	365	6311		66	

* Stations outside the Archipelago.
[1] Wire-soundings before 3 April 1930

+ Soundings with wire 1,55 mm.
× Soundings with wire 4,0 mm.

TABLE II^A

Like Tabel II, but all wire-soundings corrected for diameter measuring wheel 173.0 mm.

Station	Wire-depth	Wire-Atlas		mean	Station	Wire-depth	Wire-Atlas		mean
		+	—				+	—	
280	363	8			152	1979		12	2000 m, —18
280	382	3			348_{I}	2218		15	
51	391		28		39_{a}	2269	70		2250 m, —19
107	392		31		336	2383	34		
124_{I}	394	20		400 m, + 1	368	2458		40	2500 m, —20
44	402		16		13	2488		62	
278	481		29	450 m, 0	361	2627		5	2600 m, —21
test	490	21			79	2603		93	
test	490	20		500 m, — 1	77	2778		62	2800 m, —22
278	497		32		118	2910	32		
279_{I}	499		5	550 m, — 2	153	2951		49	
111	559	21			328	2960	18		
98	563	5		600 m, — 4	227	2964	5		3000 m, —23
283	574		23		347	3062		3	
108	575	3		650 m, — 5	379	3318		3	3250 m, —24
277	599	22			380	3318		43	
85	677		6	700 m, — 6	359	3552		24	3500 m, —25
92	685	55			305	3580	22		
29	684		10	750 m, — 8	221	3658		46	3750 m, — 26
172	726		48		65	3952	6		
106	718		90	800 m, — 9	64	4268		110	4000 m, —27
105	930		15		218	4398		26	4100 m, —28
138	953		10	950 m, —10	358	4463		2	4450 m, —29
16	1086	3		1000 m, —11	369	4477		68	
132	1321		13	1100 m, —12	66	4447		31	
89	1409		43	1200 m, —13	303	4520	65		
375	1432		47	1250 m, —14	66	4508		105	
128	1444		26	1500 m, —15	80	4584	38		
327	1453	3			75	4743		115	4600 m, —30
109	1502		23		210	4919	13		4800 m, —31
84	1518		69	1600 m, —16	331	5010		(137)	
112	1533	23			56	4971		92	
370	1704		40	1800 m, —17	52	4980		54	5000 m, —32
233	1805	37			235	5037		19	
156	1852		7		251	5084		61	5300 m, —33
30	1836	30			48	5473		15	
154	1971		(176)		365	6311		66	5500 m, —34

TABLE III

Comparisions between thermometrical- and Atlasdepths, if good opportunity for comparision, arranged according to depth.

Station	Therm. depth	Therm.- Atlas +	Therm.- Atlas —	mean	Station	Therm. depth	Therm.- Atlas +	Therm.- Atlas —	mean
339	398		73		192	2552		19	2600 m, —47
176	637		17		350	2558		65	
300	665	11			334	2658		60	
295	808		96		131*	2901		34	
151	896		47		153	2928		72	
134	939		82		328	2942		0	
138	946		17	1000 m, —36	227	2967	8		3000 m, —47
140	1071		13		214	3002		87	
364	1071		35	1100 m, —37	347	3061		4	
224	1085	13			187	3098		94	
135	1155		42	1200 m, —38	160	3221	12		
148*	1201		39		159	3250	21		
132*	1303		31	1300 m, —39	376	3292		51	
170	1361		70		163	3296		52	
230	1402		0	1400 m, —40	104	3296		46	
375	1422		57		155	3298		102	
327	1445		5	1500 m, —41	296	3322		116	
299	1495		6		377	3347		71	
370	1685		59	1600 m, —42	167	3448		132	3500 m, —47
233	1761		7		305	3507		51	
130*	1826		60	1700 m, —43	359	3549		27	
294	1825		113		221	3649		55	
156	1856		23	1800 m, —43	164	3834	22		
353	1872		67		202	3898	38		
152	1918		73	1900 m. —44	179	3947		126	4000 m, —46
285	1949		57		218	4404		20	
154	1976		(171)		303	4419		36	4400 m, —45
191	1991		54		330	4450		42	
325	1996		91	2000 m, —44	358	4467	2		
162	2008		97		369	4468		77	
324	2139		91	2100 m, —45	232	4596		57	4800 m. —44
348	2198		35		210	4907	1		
288	2201		78	2200 m, —46	212	4968		35	
336	2378	29			331	5026		121	
368	2451		47	2300 m, —46	197	5133	39		5200 m, —43
344	2479		45		146*	5371	32		
340	2510		39	2400 m, —46	365	6313		64	5500 m, —42
297	2541		83						
				2500 m, —47					

* Stations outside the Archipelago.

TABLE IV

Comparisions between Wire- and Thermometrical depths, if good opportunity for comparision, arranged according to depth.

Station	Wire-depth	Wire-Therm. +	Wire-Therm. —	mean	Station	Wire-depth	Wire-Therm. +	Wire-Therm. —	mean
165	437	2			374	2520	11		
346	500	8			334	2672	14		
354	591	12		800 m, +15	228	2675	(85)		2700 m, +13
298	829	23			153	2951	23 .		
293	851	4			328	2960	18		2900 m, +12
182	891	1			227	2964		3	
363	930	32		1000 m, +15	214	3016	14		3000 m, +11
213	1185	50			347	3062	1		
207	1214	28			237	3165		3	3200 m, +10
132	1325	22			322	3337	23		
354a	1364		1		104	3450	(154)		3300 m, + 9
149	1366	3			359	3552	3		
190	1410	3			305	3580	(73)		3500 m, + 8
375	1432	10			236	3618	21		3600 m, + 7
327	1453	8		1500 m, +15	221	3658	9		3700 m, + 6
357	1582	3			205	3916		20	3800 m, + 5
193	1677		12		218	4398		6	4000 m, + 4
370	1704	19			358	4463		4	4100 m, + 3
233	1805	44			369	4477	9		4300 m, + 2
142	1825	4			303	4520	(101)		4400 m, + 1
189	1866	4			232	4588		8	4500 m, 0
154	1971		5		210	4919	12		4600 m, — 1
152	1979	61		2000 m, +15	331	5010		16	4700 m, — 2
211	2059	34			229	5135	2		4800 m, — 3
166	2004	2			145	5698		24	4900 m, — 4
336	2383	5			365	6311		2	5100 m, — 5
368	2458	7		2500 m. +14					

TABLE V

Differences between Wire- and Atlasdepths according to Table II, decreased with the mean differences, arranged chronologically.

Station	Wire—Atlas +	Wire—Atlas —	mean	Station	Wire—Atlas +	Wire—Atlas —	mean
13		23		210	27		
16	23			218		13	
29		1		221		34	
30	59			227	16		
39a	104			test	21		
44		11		test	20		
48	50			233	47		
51		25		235		5	
52	5			251		47	
56		32		277	26		+ 5
64		58	+ 1	278		29	
65	53			278		32	
66	22			279_1		4	
66		50		280	7		
75		58		280	2		
77		24		283		20	
79		58		303	79		
80	94			305	34		
84		46		327	12		
85	5			328	29		
89		21		336	45		
92	65			347	8		
98	13			348_1		5	
105		1		358	11		
106		81		359		12	
107		28		361	6		— 6
108	11			368		29	
109		3		369		55	
111	28			370		31	
112	42			375		38	
118	58		+ 2	379	9		
124_1	21			380		31	
128		11					
132		0					
138		0					
152		2					
153		38					
156	3						
172		21					

TABLE V^A

Differences between Wire- and Atlasdepths according to Table IIa, decreased with the mean differences, arranged chronologically.

Station	Wire—Atias		mean	Station	Wire—Atlas		mean
	+	—			+	—	
13		42		210	45		
16	15			218	3		
29		4		221		20	
30	47			227	28		
39a	89			test	22		
44		17		test	21		
48	19			233	54		
51		29		235	13		
52		22		251		29	+ 13
56		60	— 16	277	26		
64		81		278		31	
65	33			278		28	
66		2		279_1		4	
66		76		280	7		
75		84		280	2		
77		40		283		21	
79		72		303	95		
80	68			305	47		
84		54		327	18		
85		0		328	41		
89		28		336	53		
92	61			347	20		
98	7			348_1	4		
105		5		358	27		
106		82		359	1		
107		32		361	16		+ 5
108	6			368		20	
109		8		369		39	
111	25			370		23	
112	38		0	375		32	
118	55			379	21		
124_1	19			380		19	
128		11					
132	1						
138		0					
152	6						
153		26					
156	10						
172		41					

TABLE VI

Differences between Thermometrical and Atlasdepths according to Table III, decreased with the mean differences, arranged chronologically.

Station	Therm.—Atlas +	Therm.—Atlas —	mean	Station	Therm.—Atlas +	Therm.—Atlas —	mean
104	1			324		46	
130		17		325		47	
131	13			327	35		
132	8			328	47		
134		46		330	3		
135	4			331		77	
138	19			334		13	
140	24			336	75		
146	75			339		37	
148		1		340	8		
151		11		344	2		
152		29	0	347	43		— 3
153		25		348	10		
155		55		350		18	
156	20			353		23	
159	68			358	47		
160	59			359	20		
162		53		364	2		
163		5		368		1	
164	69			369		32	
167		85		370		16	
170		31		375		17	
176	19			376		4	
179		80		377		24	
187		47					
191		10					
192	28						
197	82						
202	85						
210	45						
212	9						
214		40					
218	25						
221		8					
224	49						
227	55						
230	40		+ 3				
232		12					
233	36						
285		13					
288		32					
294		70					
295		60					
296		69					
297		36					
299	34						
300	47						
303	9						
305		4					

TABLE VII

Differences between Wire- and Thermometrical depths according to Table IV, decreased with the mean differences, arranged chronologically.

Station	Wire—Therm.		mean	Station	Wire—Therm.		mean	
	+	—			+	—		
132	7			233	29			
142		11		236	14			
145		12		237		13		
149		12		293		11		
152	46			298	8		—1	
153	11			322	14			
154		20		327		7		
166		13		328	6			
182		14		331		11		
189		11		334	1			
190		12	+ 1	336		9		—1
193		27		347		10		
205		24		354a		16		
207	13			357		12		
210	16			358		5		
211	19			359		5		
213	35			363	17		—2	
214	3			365	10			
218		8		368		7		
221	2			369	8			
227		14		370	4			
229	7			374		3		
232		7		375		5		

TABLE VIII

Comparisions between simultaneously observed Hughes- and Atlas echodistances and wiredepths.

Depth	A — H +	A — H —	W — H +	W — H —	
185	2				
208		3			
210	7				
215	26				
220	4				
224		48			
233	14				
233		1			
235	8				
235		8			
238	20				
243	27		28		
248		19			
253	0				
260	3				
272	6				
275	83				
280	81				
280	14				
282	9				
287		5			
292	30				
295	67				
295	9				
297		10			
297	5				
305	5		6		
307			8		
307	0				
315	5		15		
315	6				
315	1				
317			28		
320	92				
330	12				
341	2				
360	24				
385		8			
400	10		5		
415	6				
437	17				
442		49			
452		18			
470		4			
510	43				
510		8	10		
534	60				
300—500	12	4			test Maitara
	36				

mean difference A—H about + 10

Depth	A — H +	A — H —	W — H +	W — H —	
534		33			
550	32				
558		17			
654	11				
665	84				
665		42			
741	12				
750	56				
750	56				
750	56				
801		6			
801		6			
809	22				
850		23			
862		36			
876	0				
876		3			
876		3			
876	42				
889		36			
901	22				
901	27				
901	22				
901	20				
901	23				
994		21			
1050		49			
1062		9			
1079		45	7		
1090		7		20	
1160		12			
1967		16			
2317	2				
2416	12				
2435	36				
2455	23				
2462		8			
2480	27				
2482	37				
2494	8				
2500	73				
2634	24				
2645		46			
2679		21			
2695	6				
2742	12				
± 490		21	0		test Makian-Moti
		20			

mean difference A—H about + 10

These observations were taken almost exclusively before and in the beginning of the expedition. The Atlas soundings were not corrected for the estimated mean personal deviations.

Probable error of one difference A—H, after diminishing the Atlassoundings with 10 m, is 20 m.

TABLE IX

Errors in Atlasdepths, sounded over flat, horizontal bottom.

Station	True depth	v	Station	True depth	v	Station	True depth	v
132	1303	— 4	232	4595	+ 23	336	2377	— 63
152	1922	+ 34	233	1764	— 31	347	3060	— 30
153	2929	+ 36	278	481	+ 15	348_1	2198	0
210	4908	— 37	278	497	+ 18	353	1871	+ 33
212	4968	0	279_1	499	— 9 —3	358	4467	— 37
214	3003	+ 51	280	382	— 17	361	2627	— 30
218	4403	— 14	280_1	363	— 22	365	6313	+ 29
221	3649	+ 20	327	1444	— 29	368	2450	+ 13
227	2965	— 41	334	2658	+ 25	369	4469	+ 41
						370	1685	+ 24
						375	1421	+ 23

mean + 1 (r_o = 5)
probable error of one Atlassounding = 24 m.

TABLE X

Influence of current on Wiredepth.

Approximated depth	Current	Corrected Wiredepth is too large	Approximated depth	Current	Corrected Wiredepth is too large	Approximated depth	Current	Corrected Wiredepth is too large
271	strong cur	80	1828	cur	106	3098	cur	— 13
398	strong cur	129	1963	cur	9	3221	cur	— 5
440	cur	28	1981	cur	122	3250	cur	— 34
482	cur	189	1991	cur	24	3292	cur	9
494	2	76	2003	2	157	3295	cur	84
624	cur	— 8	2061	¼	65	3298	cur	24
668	1¼	17	2139	cur	— 4	3322	2	53
790	cur	30	2201	½	5	3347	cur	22
808	½	110	2216	1½	— 16	3448	1	— 21
939	2	— 9	2327	½	— 40	3500	1½	19
940	cur	31	2443	2	46	3541	¼	1
969	cur	9	2479	1	9	3556	¾	— 1
1018	cur	13	2510	1	— 6	3663	½ à ¾	22
1071	cur	— 13	2541	2	62	3675	cur	— 28
1085	¼	24	2552	cur	50	3834	1	56
1094	½	— 4	2558	½	20	3893	½	— 20
1116	cur	231	2559	½	69	3947	cur	19
1142	1½	— 57	2581	¾	21	3972	cur	80
1155	1	— 19	2585	1	6	4147	cur	— 39
1201	cur	— 22	2691	cur	82	4352	1	29
1205	1¼	— 8	2694	1½	13	4419	1/8	100
1401	cur	10	2726	cur	— 24	4610	cur	123
1437	cur	89	2804	½	— 13	4657	cur	99
1495	2	70	2832	cur	— 15	4999	cur	16
1511	cur	— 7	2901	½	13	5079	cur	— 31
1825	1	58	2942	¼	5	5129	¼	61
1826	1	88	3002	¼	1	5133	2½	— 20
1848	½	47	3010	cur	— 7			
1872	cur	— 10						

mean + 29 (r_o = 5,7)
If inclination wire 0°, mean + 27 (32 comparisions).

TABLE XI

Influence of inclination of wire on Wire depth.
(Wire depth not corrected for influence of current).

Depth	0—1000		1000—2000		2000—3000		3000—4000		4000—5000	
Wire depth minus approx. depth	+	—	+	—	+	—	+	—	+	—
Inclination 0°	40	13	5	20	70	4	2	22	8	23
	39	5	2	18	4	2	12	2	6	22
	42	3	27	14	164	11	11	15	20	12
	17	64	57	27	21	20	22	64	80	7
	6	13	107	12	157	17	92	14	99	7
	15		47	22	111	8	71	28	103	39
	1		6	14	69	15		20	30	15
	17		88	8	21	11		5	17	
	11		9	13	13				7	
	9		11	29	185					
	27				73					
	52				15					
	31									

Inclination	0—2500		2500—5000		Inclination	0—2500		2500—5000	
	+	—	+	—		+	—	+	—
5°	114	6	123	37	10°	190	6	188	22
	84	6	57	15		16	49	84	60
	60	22	20	49		9	14	20	10
	85	16	15	6		2	23	20	
	12	16	52	24		4	8	47	
	51	7	61	31		12	9	28	
	44	10	100	14		1	7	45	
	10	4	13	29		2	17	104	
	11	4	6	2		9		13	
	17	7	9	15		13		53	
	33		23	4				37	
	58			8					
	70			84					
	38			5					
	31			11					
				7					
				2					

Inclination	0—2500		Inclination	0—2500	
	+	—		+	—
20°	136		30°	29	
	28				
	50				
	115				

Conclusion: Corrections for inclination of wire are independent of the depth.
Inclination 0°—10°, correction —20
„ 15°, „ —30
„ 20°, „ —70

TABLE XII

Errors in corrected Wire depths.

Station	Approximate depth	Corrected Wire depth	v	Station	Approximate depth	Corrected Wire depth	v
104	3296	3431	+ 135	233	1761	1788	+ 27
105	910	927	+ 17	262	9994	9970	— 24
115	2047	2052	+ 5	285	1949	1995	+ 46
118	2843	2902	+ 59	288	2201	2178	— 23
130	1826	1887	+ 61	299	1495	1536	+ 41
131	2901	2884	— 17	303	4419	4500	+ 81
132	1303	1308	+ 5	305	3507	3571	+ 64
135	1155	1106	— 49	309_1	5105	5131	+ 26
138	946	929	— 17	327	1445	1426	— 19
140	1071	1038	— 33	328	2942	2932	— 10
148	1201	1152	— 49	330	4450	4436	— 14
151	896	853	— 43	334	2658	2655	— 3
152	1918	1952	+ 34	340	2510	2574	+ 64
153	2928	2918	— 10	344	2479	2459	— 20
156	1856	1852	— 4	347	3061	3040	— 21
160	3221	3193	— 28	348_1	2198	2203	+ 5
170	1361	1343	— 18	350	2558	2559	+ 1
176	637	614	— 23	353	1872	1842	— 30
191	1991	1988	— 3	358	4467	4463	— 4
192	2552	2552	0	359	3549	3533	— 16
203	3500	3491	— 9	361	2629	2611	— 18
210	4907	4911	+ 3	365	6313	6307	— 6
221	3649	3646	— 3	368	2451	2442	— 9
224	1085	1079	— 6	370	1685	1677	— 8
test	460	463	+ 3	375	1422	1405	— 17
230	1402	1386	— 16	376	3292	3283	— 9
232	4596	4578	— 18	377	3347	3339	— 8

mean difference + 1

probable error of one wire sounding 23 m.

TABLE XIII

Differences between true depth and corrected echo distance, sounded over sloping or rugged bottom.

True depth	True depth minus corr. echo distance		True depth	True depth minus corr. echo distance	
	+	—		+	—
435	53		1579	14	
440	43		1641	56	
474	34		1821		78
492	85		1862		16
548	59		1963	23	
555		69	2002		14
579	61		2025	15	
668		28	2216		3
806		8	2509		101
847	74		2564	28	
890		38	2694		14
900		50	2720	67	
940	19		2736	68	
979		59	2804	71	
1018	8		2830	127	
1094		39	2969	59	
1098	17		3168	44	
1135		13	3314		71
1186		10	3556	360	
1236	107		3596	126	
1363		9	3930		37
1401	25		5133	22	
1407		32	5721		223
1511	32		5721		43

mean difference + 11 ($r_o = 8$)

probable error of one Atlassounding 55 m.

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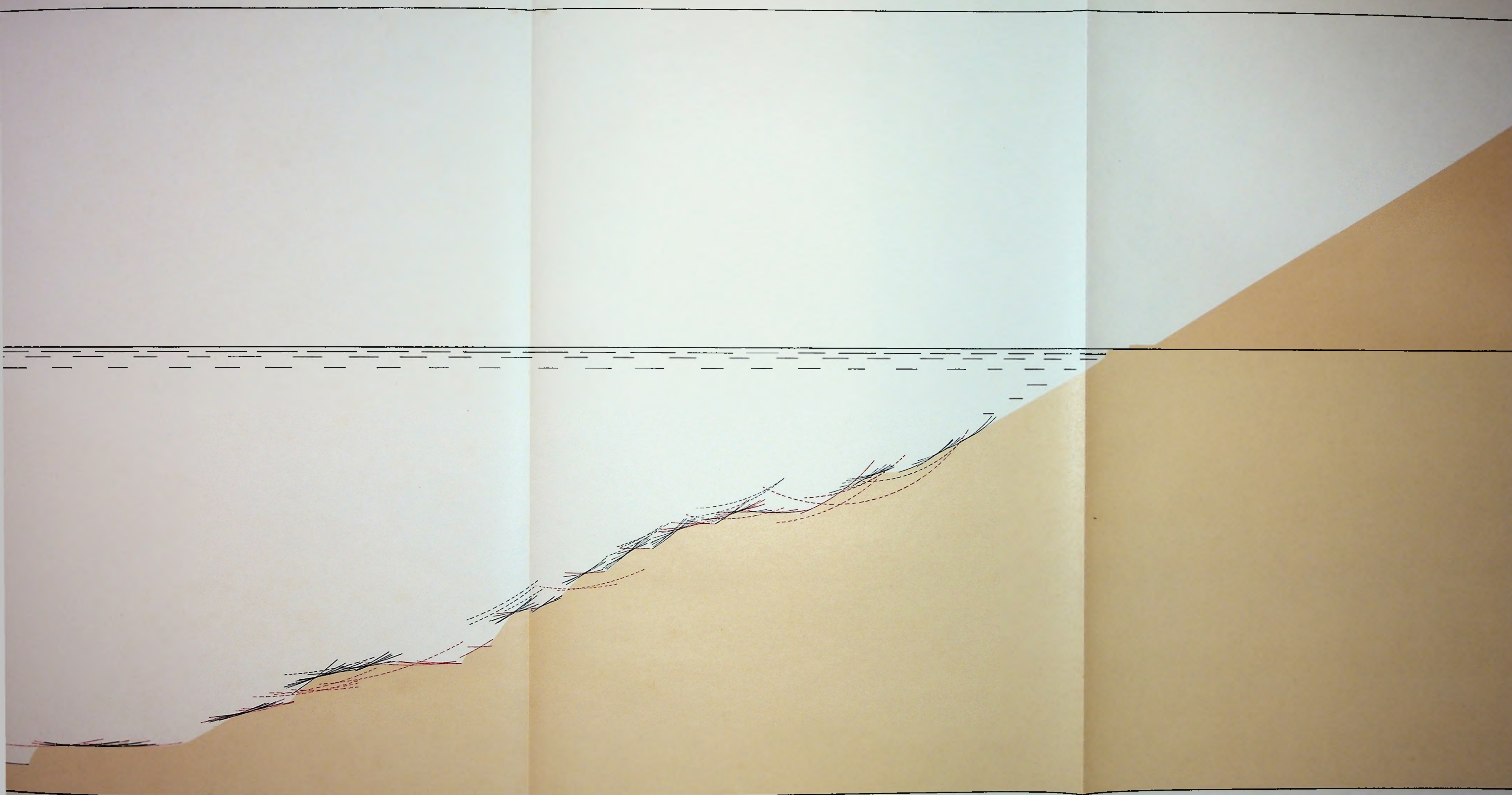

1935.

Plate I.

BOTTOM SECTION MANADO TOEA

(Scale ± 1:10.000)


THE GRANGE
PARRAMATTA

SNELLIUS-EXPEDITIE

WETENSCHAPPELIJKE UITKOMSTEN DER SNELLIUS-EXPEDITIE

ONDER LEIDING VAN

P. M. VAN RIEL

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VERZAMELD IN HET OOSTELIJKE GEDEELTE VAN NEDERLANDSCH OOST-INDIË
AAN BOORD VAN H. M. WILLEBRORD SNELLIUS

ONDER COMMANDO VAN

F. PINKE

LUITENANT TER ZEE DER 1e KLASSE

1929–1930

UITGEGEVEN DOOR DE MAATSCHAPPIJ TER BEVORDERING VAN HET NATUURKUNDIG ONDERZOEK DER NEDERLANDSCHE KOLONIËN EN HET KONINKLIJK NEDERLANDSCH AARDRIJKSKUNDIG GENOOTSCHAP

GEDRUKT DOOR EN TE VERKRIJGEN BIJ
E. J. BRILL — LEIDEN

THE SNELLIUS-EXPEDITION

IN THE EASTERN PART OF THE NETHERLANDS EAST-INDIES 1929-1930

UNDER LEADERSHIP OF
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VOL. II

OCEANOGRAPHIC RESULTS

PART 2

SOUNDINGS AND BATHYMETRIC CHARTS

CHAPTER II

THE BOTTOM CONFIGURATION IN RELATION TO THE FLOW OF THE BOTTOM WATER

(WITH TWO LARGE DEPTH CHARTS AND 16 DETAIL CHARTS)

BY

P. M. VAN RIEL
(LEADER OF THE EXPEDITION)

1934

TO BE OBTAINED OF THE PRINTERS AND PUBLISHERS
E. J. BRILL — LEIDEN

ERRORS IN PLATE II.

Manipa strait. The blue colour between 2000 and 3000 metres at about 3° 44′ S. and 127° 32′ E. is too dark.

Halmahera sea. The colour of the rise at 0° 55′ N. and 129° 37′ E. is too dark; the depth is less than 2000 metres.

The colour of the depression at 0° 47′ N. and 129° 36′ E. is too light; the depth is more than 2000 metres.

Indian Ocean. The colour of the small rise at 12° 05′ S. and 114° 15′ E. is too dark; the depth is less than 4000 metres.

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PREFACE

To meet the wish, expressed from various quarters for a speedy publication of the new depth charts, the author has composed this chapter before giving a description of the programm of research, the voyage of the ship and a general view of the observations carried out during the expedition.

For verifying the depth charts the properties of the sea water at different stations and in different depths have been used. Consequently the composion of this chapter had to be preceded by a critical examination of all temperature and salinity observations and the drawing of preliminary curves and horizontal and vertical sections, whilst the depths of serial and bottom observations had to be corrected by a comparison with those estimated by readings of both protected and unprotected thermometers. Moreover the accuracy of the various methods of sounding had to be taken into account. Dr. Hamaker, the physicist of the expedition, kindly assisted me in this preparatory work.

In order to further a rapid publication the flow of the bottom water and the nature of the surface of the sea floor will be dealt with in another chapter.

I offer my hearty thanks to Professor Dr. E. van Everdingen, Director of the Royal Netherlands Meteorological Office, for reading the manuscript and to Captain J. L. H. Luymes R. N., Chief of the Hydrographic Department of the Ministry of Defence, for the valuable assistance of his Service.

Further I owe many thanks to Raad-adviseur A. van Hengel, Director of the Topographic Service, for putting all facilities that could be provided by his Staff at my disposal. Owing to this we were able to add a large number of coloured charts to this Chapter.

For his great assistance, which was not restricted to mere clerical work, I feel much indebted to my assistant Mr. L. van Eyck.

De Bilt, July 1934. v. R.

A. INTRODUCTION

a. HISTORICAL REVIEW.

In the publication de "Zeeën van Nederlandsch Oost-Indië" S. P. L'Honoré Naber (Bibl. 21) gives an extensive review of the deep-sea soundings, collected in the Indian Archipelago by successive oceanographic expeditions or on board surveying, cable and other foreign and Netherlands ships. From those carried out before 1899, I would mention the results of the Challenger Expedition (1874—1875), the German ship "Gazelle" (1875) and the British ship "Blake" (1877—1880).

However important these results have been, it appears that before 1900, the number of deep-sea soundings were inadequate to draw a reliable map of the configuration of the sea floor of the eastern part of the Archipelago. In 1882 O. Krümmel (Bibl. 1) published a map in the "Zeitschrift für Wissenschaftliche Geographie", based on soundings of the British Admiralty Charts. J. F. Niermeyer (Bibl. 3) amplified these data by soundings derived from Netherlands charts in 1886. In the "Tijdschrift van het Nederlandsch Aardrijkskundig Genootschap" R. Schuiling (Bibl. 4) added to his article: "De grenslijn van Wallace een continentale grens", and that of C. M. Kan: "Bodemgesteldheid der eilanden en diepten der zeeën van den Indischen Archipel" (Bibl. 5) a depth chart of the whole Archipelago. This chart was compiled from the drawings by O. Krümmel and Berghaus' "Physik. Atlas".

Important sounding work was carried out by the "Valdivia" (1899), during the Siboga-expedition, directed by M. Weber (1899—1900) and by the Netherlands surveying ship "Bali" (1901).

With Part III of the "Siboga"-publication in 1902 appeared the first large bathymetric charts of the Archipelago, drawn by the naval chief of the expedition, G. F. Tydeman and based on previous soundings and those of the three above mentioned ships.

Chart 1. Depth of the sea in the Eastern Part of the Indian Archipelago. Scale 1 : 3.000.000.

Chart 2. Depth of the sea in the Indian Archipelago. Scale 1 : 5.000.000.

Chart 3. A chart giving the more detailed bottom configuration of the southern part of the Sulu Group, Manipa Strait, Kai Islands, Lombok Strait and the Postillon and Paternoster Groups. Scale 1 : 1.000.000.

In 1900 M. Weber (Bibl. 6) had published a sketch of the sea floor of the eastern part in "Peterm. Geogr. Mitteilungen", which, as the author remarks, "keinen Anspruch auf grössere Genauigkeit erhebt".

G. Schott (Bibl. 9), when reviewing the first publications of the Siboga-expedition, in 1904 published in the "Annalen der Hydrographie" a depth chart of the eastern part of the Archipelago after Tydeman's chart.

The Siboga-expedition must be regarded as a milestone in the investigation of the East-Indies. Of the ships which have contributed subsequently most to the enlargement of our knowledge of the Indian sea floor, L'Honoré Naber mentions further the Netherlands man of war "Edi" (1903), the German ship "Stephan" (1905), the Netherlands surveying ship "Bali" (1905), the German research ship "Planet" (1906—1907), the British ship "Fantome" (1907), the "Magnet", belonging to the "Eastern Extension Company" and the Netherlands cable-ship "Telegraaf" (1910—1917).

J. F. Niermeyer (Bibl. 11) deals with the results of the "Edi" (1903), "Stephan" (1905) and "Planet" (1906—1907) in his article: "Diepzeeloodingen in en nabij den Oost-Indischen Archipel", "Tijdschrift van het Aardrijkskundig Genootschap", 1907, p. 872. To this article has been added

a depth chart ("Kaart XI") of the region east of the Philippines, drawn by C. Craandijk. Scale 1 : 924.000. This chart is based on "Tafel I", published by G. Schott and P. Perlewitz (Bibl. 10) in 1906, and on the soundings of the "Planet".

As an appendix to the article by J. F. Niermeyer (Bibl. 12) a chart on a scale 1 : 2.500.000 by C. Craandijk appeared in 1909 (Bibl. 13) which embraces the basins and troughs surrounding the island Celebes. This chart contains especially in the Gulf of Tomini and in the Peleng strait between Celebes and the Banggai group, important improvements. A reproduction of this chart is also to be found on the geological chart of the whole Archipelago, composed by E. C. Abendanon in 1914 (Bibl. 19).

The last separate depth chart of the East Indian Archipelago composed by Vice-Admiral G. F. Tydeman embraces the whole region from 12° 30′ S. to 12° 0′ N. and from 94° 0′ to 141° 0′ E., scale 1 : 10.000.000 (Bibl. 21). A similar depth chart, published by G. A. F. Molengraaff (Bibl. 20) in 1921 in "The Geographical Journal" gives not only the configuration of the sea floor, but also of that portion of the globe in the Archipelago which lies above sea level.

Beside the investigations, carried out by the above mentioned and other ships, important surveying work in the coastal waters has been done during a long succession of years by the "Netherlands Hydrographic Service" in the East-Indies. The soundings on the shelf in the vicinity of British Borneo and the Philippine islands, carried out by the Hydrographic Services of Great Britain and the United States, are also of great value.

Though the depth chart of the eastern part of the Archipelago has been improved gradually during the first quarter of this century, the number of deep-sea soundings outside the 200-metre line did not amount before 1929 to more than one sounding per 1000 square kilometres. However important previous depth charts have been for our knowledge of the topography of the sea floor in this region, the material on which they were based was out of all proportion to the complexity of the sea floor. A very great increase in the number of soundings could not be expected with the technical means used hitherto. Only the application of echo-sounding installations could enable a great stride forward to be made in procuring observations. Most happily the Snellius-expedition had two systems of echo-sounding at its disposal.

b. WORK CARRIED OUT DURING THE EXPEDITION.

The sounding work and the correction and plotting on fair sheets of the great number of soundings was carried out by the nautical staff and the crew of the "Snellius" under the direction of Commander F. Pinke. In Volume I, Chapter II, a full account will be given by him of the sounding installations; in Volume II, Chapter I of Part 2 of the methods followed and the accuracy of the observations.

If the investigation had been limited to soundings only, the track of the ship would have shown parallel lines at about equal distances and as nearly as possible at right angles to the supposed direction of the depth contours. The distribution of the soundings on the depth charts does not always point to such a method having been pursued. In the first place another requirement had to be considered by the author, when fixing the track, i.e.: the right distribution of the oceanographic stations in the field of research. Fortunately both requirements could often be met at the same time.

In entrances and passages, when detailed sounding work was necessary to determine the deepest spot of the sills on which the properties of the abyssal layers in basins and troughs depend, the exigencies of surveying prevailed.

During the expedition I had a set of charts at my disposal, drawn on a large scale, on which all deep soundings known before leaving Holland had been inserted. In the course of the research work as many "Snellius"-soundings as possible have been plotted on these charts. I am much indebted to petty-officer Woltering, for always keeping the charts up to date, as these working charts have been of much value to me. They allowed the drawing of provisional depth contours and, when fixing the next tracks to be followed in regions visited before, I was able to take into consideration previous results and to fix the position of the next stations in better relation to the true bottom configuration.

The second set of charts, kept with much care by Lieutenant F. H. M. van Straelen, served for

plotting the track of the ship, and were based on observations of celestial bodies, bearings or dead reckoning, corrected for the observed surface current.

The third and most important set of charts served as a basis for constructing the annexed depth charts and consisted of the following fair sheets:

FAIR SHEETS

No.	Area	Limits		Scale
		Latitude	Longitude	
1	Makassar strait	2°40′ N.— 5°20′ S.	117°00′—121°30′ E.	1 : 1.000.000
2	Celebes sea	0°30′ N.— 8°00′ N.	117°00′—126°00′ E.	1 : 1.000.000
3	Sibutu passage	4°30′ N.— 5°10′ N.	119°25′—119°55′ E.	1 : 100.000
4	Mindanao and Sangihe trough	1°00′ N.— 9°00′ N.	124°00′—130°00′ E.	1 : 1.000.000
5	Mindanao trough, deepest spot	8°50′ N.— 9°50′ N.	126°40′—127°10′ E.	1 : 150.000
6	Molukken, Halmahera and Ceram sea	4°00′ N.— 4°00′ S.	125°00′—133°00′ E.	1 : 1.000.000
7	Seas surrounding Boeroe	0°40′ S.— 4°20′ S.	124°10′—129°30′ E.	1 : 500.000
8	Southern Molukken and Northern Banda sea	1°00′ N.— 5°00′ S.	120°00′—128°00′ E.	1 : 1.000.000
9	Banda sea	3°00′ S.—11°00′ S.	125°00′—135°00′ E.	1 : 1.000.000
10	Goenoeng Api	6°32′ S.— 6°46′ S.	126°30′—126°50′ E.	1 : 50.000
11	Flores and Sawoe sea	4°00′ S.—12°00′ S.	116°00′—126°00′ E.	1 : 1.000.000
12	Entrance to Timor sea	10°40′ S.—11°50′ S.	122°00′—123°30′ E.	1 : 200.000
13	Dao strait	10°10′ S.—11°10′ S.	121°50′—123°10′ E.	1 : 200.000
14	Sawoe strait	9°50′ S.—11°00′ S.	120°20′—122°00′ E.	1 : 200.000
15	Ombai strait	8°00′ S.—10°00′ S.	123°00′—126°00′ E.	1 : 500.000
16	Toekangbesi Is.	4°40′ S.— 6°40′ S.	123°00′—125°00′ E.	1 : 250.000
17	Bali sea	4°00′ S.—12°00′ S.	112°00′—118°00′ E.	1 : 1.000.000

All previous deep-sea soundings have been plotted on these fair sheets by Lieutenant J. P. H. Perks.

The 200-metre line has been constructed by copying it from various large scale charts and surveying results not yet published. In those areas only where the 100-fathom line lies close to the shore, this depth contour has been regarded as 200-metre line; in other instances the difference has been taken into account.

The copying of this 200-metre line led to the discovery of some deep-sea soundings which had been overlooked. In all about 3500 deep soundings were available before starting the expedition. This number has been increased tenfold by the "Snellius"-material.

Of this material as many soundings as possible have been plotted on the fair sheets, principally by the same officer [1]) and depth contours have been drawn by him for every 500 metres after careful consideration. In regions where soundings are scarce, the drawing of the contours is often based on personal views; e.g. a connection may be supposed between soundings, which leads to drawing parallel troughs or ridges, whilst with the same right a representation of isolated depressions or submarine rises may be given. The contours in general have been drawn after considering the configuration of the sea floor in the vicinity, where a large number of soundings or the direction of the shore-line pointed to a definite direction of the folding of the earth's crust. When discussing the drawing of the

[1]) Commander Pinke and Lieutenant Veldman also took part in this work.

contours with Perks, I always admired the patience and care, with which he steadily and quietly pursued his work under unfavourable circumstances in his cabin below decks at hothouse temperature. His additional notes have been of much help to me when verifying the final depth charts.

Under the care of Commander Pinke fair sheets and sections were finished after my return from the East-Indies and were afterwards sent to Holland, the Department of the Navy at Batavia ("afdeeling Scheepvaart") at my request having kindly made the necessary copies from each of the fair sheets. For this assistance I owe many thanks to the Head of the Division "Scheepvaart" Mr. A. J. W. van Anrooy. In this way Dr. Kuenen, the geologist of the expedition, and myself were able to study the preliminary results appearing from the fair sheets, whilst the original sheets could be used for constructing the depth charts [1]).

c. CONSTRUCTION OF THE BATHYMETRIC CHARTS.

Owing to the ready assistance of the Hydrographic Department of the Ministry of Defence, the data on the fair sheets could be supplemented according to the latest information, received after the departure of the expedition from Holland. Additional data have been derived from:

Several U.S. and British Admiralty charts.

Soundings of the German research ships "Emden" and "Berlin", the cable-ship "Zuiderkruis" (1930, 1932) and Netherlands submarines and surveying ships.

Moreover the latest "Lists of Oceanic Depths" and the "Carte générale bathymétrique des Océans, Monaco" have been consulted.

Shortly before printing the depth charts some echo-soundings of the German cruisers "Karlsruhe" (1932/34) and "Köln" (1933) have been utilized to improve the southern sheet of Plate I for those regions where soundings were scarce. These soundings have been published in: "Beiheft zu den Nachrichten für Seefahrer nr. 25, 1934."

The velocities used for calculating the echo-distances correspond with those of the Snellius-expedition.

The compiling of the depth charts has been carried out by one of the cartographers of the Hydrograhic Department, Mr. C. Craandijk (who had already won his spurs in doing this exacting work) according to the author's indications, who undertook the final control. The fact, that the properties of the abyssal waters in the partly closed basins depend upon the depth of the deepest entrance, afforded a means of checking the estimation of this depth, where soundings were inadequate or totally lacking. According to similar oceanographic considerations and my personal views, the representation has been changed in some regions and additional depth contours have been added in order to increase the distinctness of the bottom configuration in details. For the greater part however, the depth contours on the final charts concerning the eastern part of the Archipelago, correspond with those drawn on the fair sheets by Commander Pinke and his officers. The height contours have been derived from various sources by Mr. Craandijk.

The depth charts consist of one large chart on a scale 1 : 2.500.000, extending from 10° N. to 12°30′ S. and 112°40′ to 134°20′ E. As projection the cylindrical projection with equidistant meridians and equidistant parallel of mean latitude has been chosen. For technical reasons, connected with the printing, Plate I has been divided into two sheets by the parallel of 0°35′ N.

The printing of over 32500 soundings in tables has been omitted, owing to the large expenditure involved. For this reason the number of soundings plotted on the charts is as great as possible. This has the advantage, that a representation of the sea floor, deviating from that of the present map, may be drawn according to one's own opinion.

The "Snellius"-soundings are rounded off to within ten metres and have been printed in italics, those from other sources in upright figures; the centre of the numbers represents the position of the sounding, i.e. the shortest distance to the bottom.

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[1]) These original sheets are deposited at the Hydrographic Office, Ministry of Defence, the Hague.

For those regions where the bottom configuration is very complicated and many soundings are available, the following maps, drawn on a larger scale, have been added to these two sheets:

DETAIL CHARTS

No.	Area	Limits		Scale
		Latitude	Longitude	
1	Northern entrance to Makassar strait	0°00′ N.— 2°30′ N.	118°30′—120°00′ E.	1 : 1.000.000
2	Sibutu passage	4°40′ N.— 5°01⁵′ N.	119°25′—119°50′ E.	1 : 200.000
3	Passages between N. E. Celebes and Siaoe I.	1°30′ N.— 3°00′ N.	125°00′—126°00′ E.	1 : 1.000.000
4	Passage between Tanimbar Is. and Babar I.	7°00′ S.— 9°00′ S.	129°00′—131°00′ E.	1 : 1.000.000
5	Southern entrances to Sawoe sea and Timor trough	10°00′ S.—11°30′ S.	120°40′—123°10′ E.	1 : 600.000
6	Western part of the Flores sea	7°00′ S.— 8°30′ S.	118°00′—120°00′ E.	1 : 1.000.000
7	Ombai passage	8°00′ S.— 9°15′ S.	124°00′—126°00′ E.	1 : 1.000.000
8	Eastern part of the Flores sea.	6°50′ S.— 8°30′ S.	121°00′—123°00′ E.	1 : 1.000.000
9	Toekangbesi Is.	5°00′ S.— 7°00′ S.	123°00′—125°00′ E.	1 : 1.000.000
10	Passage between Boeroe and Sanana	2°20′ S.— 3°10′ S.	125°40′—126°20′ E.	1 : 500.000
11	Lifamatola strait	1°20′ S.— 2°00′ S.	126°20′—127°30′ E.	1 : 500.000
12	Manipa strait	2°50′ S.— 4°30′ S.	126°50′—128°20′ E.	1 : 500.000
13	Entrance to the Molukken sea	2°30′ N.— 5°00′ N.	127°00′—129°00′ E.	1 : 1.000.000
14	Mindanao trough	9°35′ N.— 9°44′ N.	126°44′—126°57′ E.	1 : 150.000
15	Entrances to the Celebes sea .	4°00′ N.— 6°30′ N.	125°00′—127°30′ E.	1 : 1.000.000
16	Banda-plateau	3°15′ S.— 5°00′ S.	129°30′—130°30′ E.	1 : 1.000.000

The "Snellius" *echo-distances* of more than 600 metres are on the average 35 metres too large [1]). Moreover one-half of the echo-distances have errors of less than 24 metres (Probable Error = 24 metres). The greatest error may be estimated at a hundred metres.

One-half of the ship's positions, *estimated by astronomical observations*, are affected by an error of less than half a nautical mile (926 metres); the greatest error may be estimated at 2 nautical miles.

Except for the constant error of 35 metres, one-half of the "Snellius" *echo-depths* have errors of less than 34 metres consequent upon errors, due to the fixing of the ship's position by astronomical observations, the estimation of the echo-distance and the slope of the sea floor. Or otherwise expressed: On account of the frequency of the different angles of sloping in the field of research, one-half of the echo-depths, of which the position *is based on astronomical observations*, should be shifted along a distance of less than 1300 metres to arrive at the right position. This means a distance of 0.52 millimetres on a chart drawn on a scale of 1 : 2.500.000.

The soundings plotted on the depth charts are not corrected for the constant error of 35 metres and no slope-correction has been applied.

For further details we refer to Chapter I of this Part.

The contours of 500 metres, 1500 metres, etc. have been drawn only in cases where the depth differed but slightly over a wide area or when the position and shape of the sills separating the various

[1]) For shallower depths this value is less.

basins stood out clearer in this way. Other contours have also been used on some of the detail charts, representing shallower regions. When a sequence of "Snellius"-soundings were in contradiction to previous wire soundings, the latter have not been used.

Owing to the large amount of soundings, plotted on the depth charts, no indication of the nature of the sea floor could be given. (see p. 54).

In coöperation with the Netherlands Geodetic Commission a depth chart of the whole Archipelago on a scale 1 : 5.000.000 has been added to those representing the eastern part only.

In the region embracing the Netherlands colonies, Dutch names of islands, seas, passages, etc. have been printed on the charts; this may be convenient when consulting Netherlands charts of this region. In other instances foreign names have been used.

The following abbreviations and Dutch or Malayan names have been printed on the charts:

Zee = Sea	Baai, Bi. = Bay
Diep = Deep	Bank, Bk. = Bank, Shoal
Bekken = Basin	Hoek, H., Tandjong, Tg. = Point
Trog = Trough	Karang, K. = Reef
Eilanden, Eil^{n}, E^{n} = Islands, Is.	Kampong, Kg. = Village
Riffen = Reefs, Shoals	Kaap, Kp. = Cape
Rivier, R. = River	Straat, Str. = Strait
Mond, Moeara, M. = Mouth (river)	Noord, N. = North
Golf = Gulf	Zuid, Z. = South

Pronounce: ee in "zee" as a in "state"; i in "Timor" and ie in "diep" as ee in "deep"; ei in "eiland" as i in "island" and oe in "Boeroe" as oo in "food".

In the following pages the configuration of the sea floor will be considered from an oceanographic standpoint, so that special attention will be paid to the depth of the passages through which the renewal of the bottom layers in basins and troughs takes place.

Moreover the present charts will be compared with those by Vice-Admiral Tydeman (Bibl. 21) in order to show the progress in our knowledge of the configuration of the sea floor, which is apparently of a far greater complexity than supposed hitherto.

B. CONFIGURATION OF THE SEA FLOOR

a. GENERAL REMARKS.

In the centre of the Archipelago rises the island of Celebes, surrounded by deep inland seas except on the south-western side, where the island is connected with the Asiatic continent by the contour of depth of 1000 metres. Of these inland seas we mention: Makassar strait, the Celebes sea, the Molukken sea with the Gulf of Tomini, the Banda sea with the Gulf of Bone and the Flores sea.

Outside this complex of basins and parallel to the edge of the Australian-shelf an elongated depression extends from the Ceram sea, forming the western and deeper part of the shallow Arafoera and Timor seas. As isolated basins we mention further the Halmahera sea between New-Guinea and Halmahera; the Wetar strait and Sawoe sea, which may be regarded as a continuation of the eastern part of the Banda sea (Weber deep) and finally the Sulu sea between Borneo and the Philippines.

The sea floor in some of the seas shows an extremely irregular configuration, in other parts fairly uniform depths. The greatest depth of 7440 metres has been recorded in the Weber deep.

The inland seas are separated from the adjacent oceans and from each other by submarine ridges on which lie rows of larger and smaller islands and reefs with numerous passages in between.

Much time has been spent in estimating the depth of the most important of these passages, as the properties of the abyssal waters in the inland seas depend on the depth of the deepest entrance and the properties of the water layer outside the sill. For this reason these properties had to be examined in the adjacent parts of the Pacific and Indian Ocean also; at the same time a great number of soundings could be collected here, which have added much to our knowledge of the bottom configuration in these extreme parts of both oceans.

Moreover the above mentioned relation may help us to estimate the depth of the deepest passage in a dividing ridge, where soundings are scarce or totally lacking. Owing to the slight vertical gradient, the salinity will often be less suitable for this purpose and we shall have to consider the temperature in the first place.

A comparison of the temperature *in situ* at different depths may however, as will be shown later, lead to misinterpretation of the flow of the bottom water. A correction must be applied in order to eliminate the influence of compression and *potential* temperature must be considered instead.

In order to judge rightly of the accuracy of this method, we must take into account the fact, that the properties at the same depth may change from one year to another and from season to season. To examine the order of magnitude of these variations the observations at some stations have been repeated. Variations of short periods need not be considered here.

Fig. 1, A shows the curves for potential temperature and salinity with an interval of one year, for two stations outside the entrance to the Celebes sea, north-east of Celebes (Biaro strait). The temperature at a depth equal to that of the entrance (about 1200 metres) has not much changed. A temperature of 3°.6 C. occurring at 1200 metres in the year 1929, was observed in 1230 metres in the following year.

Fig. 1, B shows the changes from May to October 1930 in the Pacific Ocean outside the entrance to the Halmahera sea. At 700 metres (the depth of the entrance) the difference in potential temperature corresponds, here also, to a difference in depth of about 30 metres.

Fig. 1, C shows the change after a lapse of one year in the Molukken sea, outside the entrance to the Ceram sea. In about 1900 metres (the depth of the entrance) the change is approximately 0°.1 C. As the vertical gradient is small, this means however a difference in depth of about 70 metres.

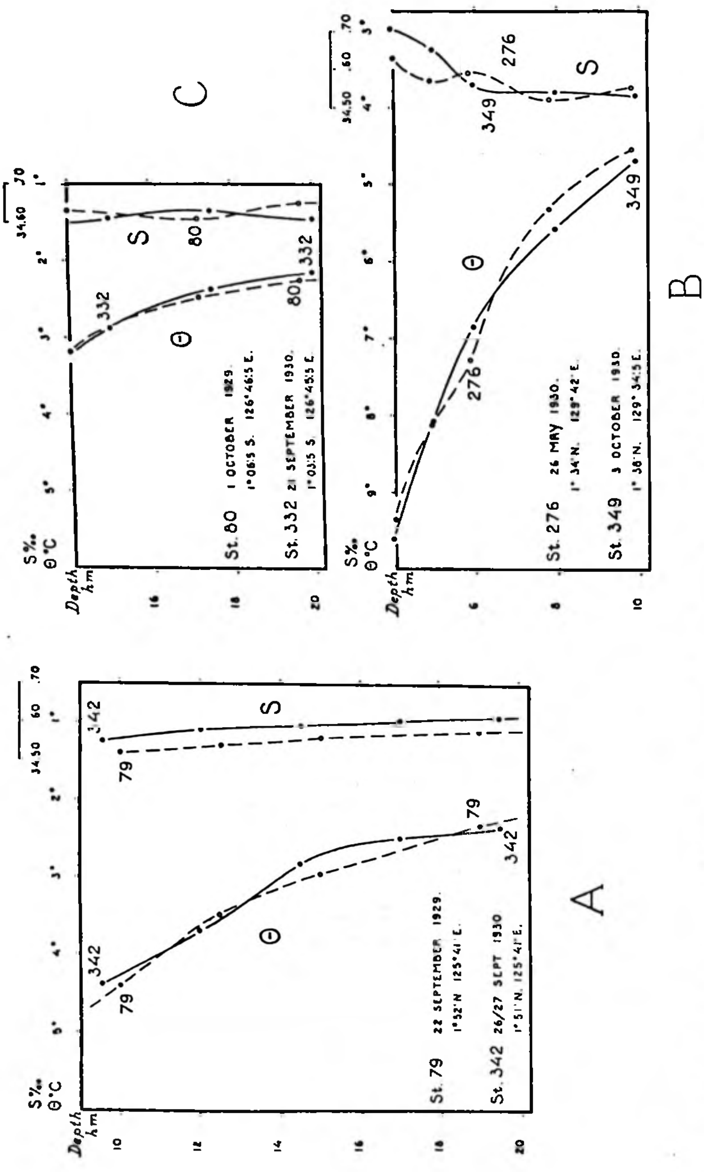

Fig. 1. Potential temperature and salinity. Comparison of observations at approximately the same place in different seasons and years.

A large number of soundings however here give reliable data as to the maximum depth of the passage. When comparing the properties inside the basin with those of the bottom water on the outside of the entrance, we must take into account the increase of the temperature owing to the exchange of heat with higher layers and with the earth's crust, during the flow of the bottom water in the entrance and along the slope to the deepest layers in the basin. Consequently the method must be regarded as an approximation, which may be of much value when the vertical gradient is not too small and soundings are scarce or lacking. According to fig. 1, the salinity does not change much with increasing depth below a level of 800 metres; in such cases the salinity distribution will not be of much use for estimating the depth of the entrance, but may be of value when *different* entrances in almost the same depths have to be considered and temperature is of no use.

The following terminology has been used in the description of the topography of the sea floor.

The *shallow sea*, surrounding the continents and islands, is bounded by the depth contour of 200 metres. Beyond this line lies the *deep sea*; the layers from 2000 metres downwards belong to the abyssal region.

The floor of the shallow sea is called the *continental-shelf,* sloping very gradually downwards as far as the 200-metre line. The zone of the margin of an island or group of islands to the same depth is called *insular-shelf.* Outside the contour of depth of 200 metres follows a steeper descent, i.e. the continental-(insular-) *slope* to a depth where the sea floor slopes very gently or presents a rather flat plain.

A *rise* is an extensive gently sloping elevation in the sea floor.

A *ridge* has a more or less elongated form and steeper sides than a rise. In a passage, connecting the inland seas, this type of the submarine ridge has been called the *sill.* The deepest spot of the sill (the *saddle*) lies in the *saddle-depth.*

A *plateau* is a flattened elevation of great extent with rather steep sides.

The name *shoal* has been used for a part of the sea floor over which the water is relatively shallow.

A *bank* is a sandy submarine elevation, dangerous to navigation, which may uncover.

The same applies to a *reef:* a rocky or coral elevation.

Any lowering of the sea floor in general is called a *depression.* When this depression has a more or less circular form the name *basin* is used.

An elongated depression is called a *trough.* Whether a depression should be called a basin or a trough is not always easily settled. The depression in the Flores sea for instance has been called a basin, according to the shape at a depth of 3000 metres. If, however, we consider the area lying below the isobatic contour of 5000 metres, the outline is more trough-shaped.

The name *deep* has been used only once, for a well-defined deepest area in the Banda sea,w here in the Weber deep the depth exceeds 3000 fathoms.

b. THE ADJACENT PART OF THE PACIFIC OCEAN [1]).

Owing to the small number of soundings, limited almost to those of the "Edi", "Stephan" and "Planet", the drawing of the contours of depth east of a line running from 0° lat. and 131° E. to 10° N. and 128° E., is somewhat hypothetical.

Judging from the sharp contrast in depth in the region investigated by the above mentioned ships between the Talaud and the Palao islands, we may presume that future soundings in the area east of Mindanao will show a bottom configuration more complicated than the representation in the present chart.

To the east of the island Morotai the "Snellius" found as a new feature an elevation on which a smallest depth has been recorded of 1990 metres; probably this elevation is connected with the Tobi-Helen-plateau.

Between the above mentioned line and the coast, the soundings of the "Snellius" throw a new light on the bottom configuration.

East of Mindanao a narrow trough runs parallel to the coastal line towards south-south-east as far as the island Halmahera. Niermeyer (Bibl. 11) uses the name "Talaud" trough for this depression and later on the name "Mindanao-Talaud" trough has been used. Schott and Perlewitz (Bibl. 10) use the first name "Talauer Graben". In Tydeman's opinion the name *Mindanao trough* is more in accordance with the position. We entirely agree with him and it is the more reasonable to maintain this name, because a new narrow and deep depression to the east of the Talaud island appears on the depth chart, which will be called *Talaud trough.*

When comparing the configuration of the Mindanao trough with the representation given by Tydeman, it appears, that this depression is deeper and extends farther to the south than was supposed hitherto. The greatest depth, recorded by the "Snellius" by echo-sounding, is 10170 metres, at about 10° N. The German research ship "Emden" found eastward of this spot for the deepest recorded echo-sounding 10830 metres. Apparantly owing to the error in fixing the position of both ships, the depth contours differ slightly as shown by detail chart 14, which has been drawn according to the computation of F. Pinke. More particulars concerning this difference will be given by him in Chapter I of Part 2.

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[1]) See appendix, p. 59.

Following the axis of the trough to the south, the depth gradually decreases and at 8°30′ N. the contour line of 9000 metres is interrupted. At 6° N. however, the greatest depth, recorded on a cross-section, is once more over 9500 metres.

On the present charts two spots to the east of the island Miangas, where we recorded more than 4000 metres, have been considered as belonging to the deep area of the Mindanao trough. Consequently the contour line of 4000 metres shows here a sharp bend towards south-west.

It is possible that this contour of depth runs parallel to the axis of the trough in correspon-

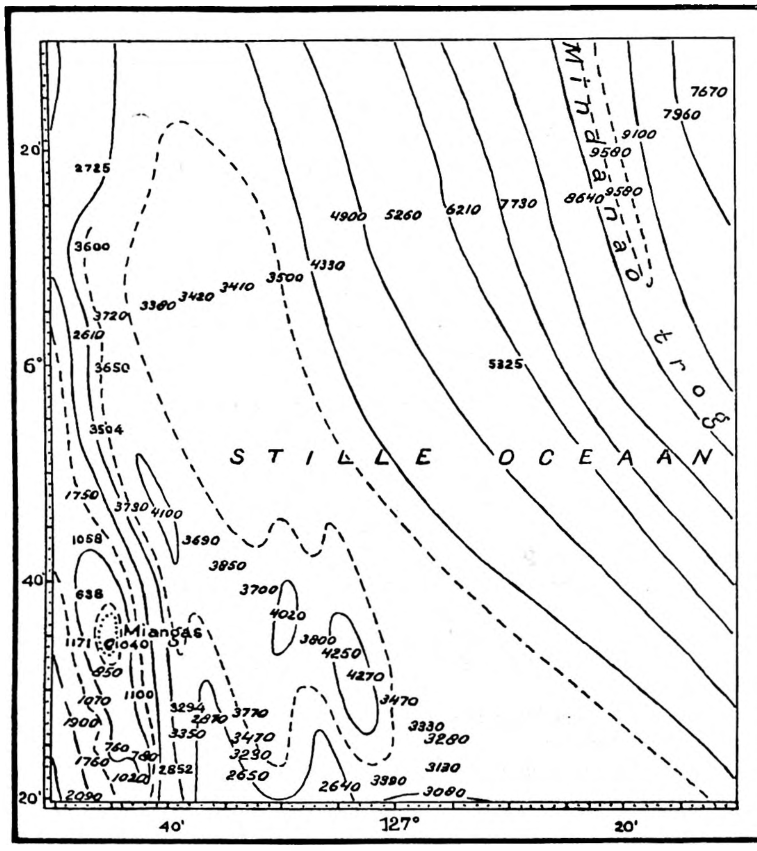

Fig. 2. Representation of the bottom configuration to the north of the Talaud islands deviating from that of the depth charts and detail chart 15.

dence with those for 5000 metres, 6000 metres, etc. Based on this assumption a second representation of the topography of the sea floor has been given in figure 2.

In drawing the 3500-metre line a deeper elongated part appears on the west side with three areas at over 4000 metres. The narrow Talaud trough may then be regarded as its southern extension and the ridge, outlined by the 3500-metre line, as a continuation of a much shallower rise towards the north. (see p. 19, Snellius ridge).

In the southern part of the Mindanao trough the depth contour of 5000 metres extends as a narrow tongue as far as 2° N. between Morotai I. and the plateau eastward of it on which soundings of 1990 metres have been recorded.

Between 4° N. and 7° N. a narrow ridge at less then 5000 metres depth appears on the east

side of the Mindanao trough. The eastern outline of this ridge is based on few observations and future soundings may show it to extend farther eastwards. A larger number of soundings at about 7° N. and 128° E. allow the drawing of an isolated and less elongated rise of the sea floor, on which soundings at less than 4000 metres have been recorded.

The sounding on Tydeman's chart at 6104 metres at about 4°30′ N. and 129° E. must be considered as wrong and has been dropped.

To give an idea of the slope of the sea floor in the deepest depression of the earth's crust, two cross-sections of the Mindanao trough have been drawn in Fig. 3 to a proportional scale, along a distance of about 100 kilometres in a direction W.S.W.—E.N.E., between the positions A—B and C—D. (see Plate III).

In order to draw the upper bottom-line a continuous line of echo-soundings has been used, taken on the ship's track B—A. The position of the ship is plotted on the line B—A for intervals of 15 minutes. From these points arcs have been constructed with a radius equal to the echo-distance according to which the bottom-line has been drawn, touching the successive arcs. The angle of slope amounts to not more than 10°, with the exception of a steeper part along a distance of 2000 metres near position B.

On either side of the axis of the trough the distances have been indicated in the figure along which the echo was weak or has not been heard at all.

The section C—D is based on the contours of depth by plotting the line C—D on the fair sheet (scale 1 : 1.000.000). At each point of intersection of C—D with the contour lines (every 500 metres) the depth has been plotted downwards and the bottom-line drawn free hand. The western (left) slope is steepest, i.e. about 15°—20°.

We now turn to the temperature observations, carried out by the "Snellius" in the Mindanao trough, which show that the extreme western part of the Pacific Ocean is separated by a submarine ridge from the open sea.

In table 1 we give the temperature and salinity observations at "Snellius"-station 262 from a depth of 1455 metres downwards to the bottom, in the Mindanao trough.

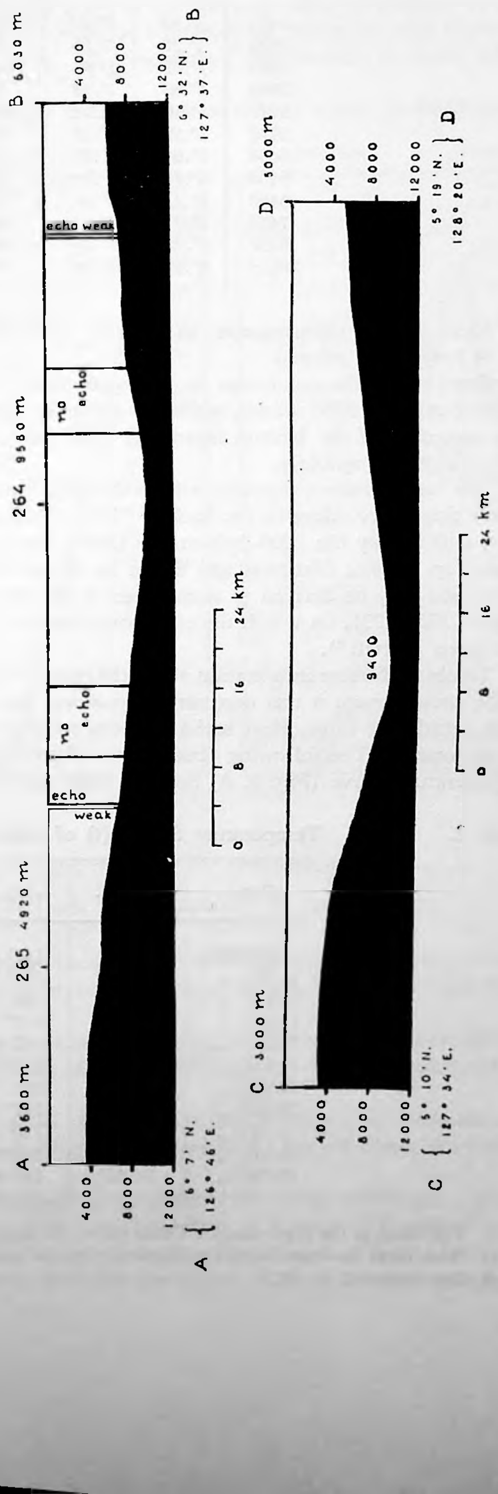

Fig. 3. True-scale bottom contours in the Mindanao trough.

Table 1. Comparison of the temperatures inside and outside the Mariana ridge.

Depth m	"Sn."st. 262			"Tuscarora"	
	t°C.	θ°C.	S °/₀₀	t°C.	θ°C.
1455	3°.20^5	3°.09^5	34.58	2°.50	2°.40
1970	2°.27	2°.13	.60^5	1°.75	1°.62
2470	1°.82^5	1°.65	.64	1°.30	1°.13
2970	1°.66	1°.44	.66	1°.00	0°.79
3470	1°.58^5	1°.31	.67	0°.85	0°.60
3970	1°.59^5	1°.26	.67	0°.80	0°.51
4450	1°.64	1°.25	.67	0°.80	0°.44
5450	1°.78	1°.26	.67		
6450	1°.92^5	1°.25	.67		
7450	2°.07^5	1°.24	.68^5		
8450	2°.23	1°.22	.69^5		
10035	2°.47^5	1°.16	.67		

Next to the temperatures *in situ* the *potential* temperatures with reference to the surface θ have been printed.

Contrary to the conditions in the open ocean a minimum temperature *in situ* has been observed at about 3500 metres, whilst the potential temperature below this depth is almost uniform, with exception of the bottom layers. At 7450 metres and 8450 metres the salinity observations show a slight irregularity.

The temperature observations show that this western part of the Pacific is isolated by a submarine ridge. According to the back of "Pilot Chart of the Indian Ocean", January 1932 [1]), this ridge, outlined by the 2000-fathom line (3660 metres), probably ranges from New-Guinea along Palao, Yap, Guam, Marianas and Bonin Is. as far as the Japanese coast [2]). Confirmation of this supposition may be derived to some extent from the back of "Pilot Chart of the North Pacific Ocean", May 1931, on which the echo-soundings of U.S.S. "Ramapo" between Guam and Japan have been plotted [3]).

To obtain further information about the depth of this ridge, especially as to the part appearing on the present map, it was necessary to compare the temperature results of the "Snellius" with those outside the ridge. Here serial temperature observations below a depth of 1500 metres are scarce however. The following observations of the "Tuscarora" furnished the data for drawing a temperature curve (Fig. 4, A) between 1500 and 4500 metres.

Table 2. Temperature *in situ* (t) of some "Tuscarora"-stations.

Date	Lat. N.	Long. E.	Depth m	t°C.
13/IV/1874	25° 55′	147° 47′	4634	0°.8
14/IV/ „	26° 18′	144° 54′	1280	2°.8
14/IV/ „	26° 18′	144° 54′	3109	1°.0
15/IV/ „	26° 28′	143° 33′	3804	0°.8
15/IV/ „	26° 41′	142° 42′	2434	1°.3
19/IV/ „	28° 56′	141° 50′	2458	1°.3
19/IV/ „	29° 56′	141° 52′	4453	0°.8
20/IV/ „	30° 29′	141° 14′	3052	1°.0
8/IV/ „	31° 18′	140° 53′	2527	1°.3
21/IV/ „	32° 13′	140° 37′	2076	1°.6
22/IV/ „	34° 31′	140° 14′	2959	1°.0

[1]) Published at the Hydrographic Office under the authority of the Secretary of the Navy, Washington, D. C.

[2]) This ridge has been called the *Mariana ridge* and the enclosed region the *Mariana basin*.

[3]) See appendix, p. 59.

From this curve we derived temperatures *in situ* (t) and *potential* temperatures (Θ) in the levels corresponding to those of "Snellius"-station 262. These data, given in Table 1 (see p. 16), enable us to draw a vertical section, representing schematically the temperature distribution, between the mean position of the "Tuscarora"-stations and "Snellius"-station 262, for the temperature *in situ* and the potential temperature. (Fig. 4, B and C).

Before discussing this figure for estimating the depth of the *Mariana ridge,* we take this opportunity to point out the necessity of making use of *potential* temperatures, when we wish to derive information about the general circulation from the temperature distribution, in cases where vertical displacements also occur.

Fig. 4, B suggests a wedge-shaped, gradually descending mass of cold water, pressing into a

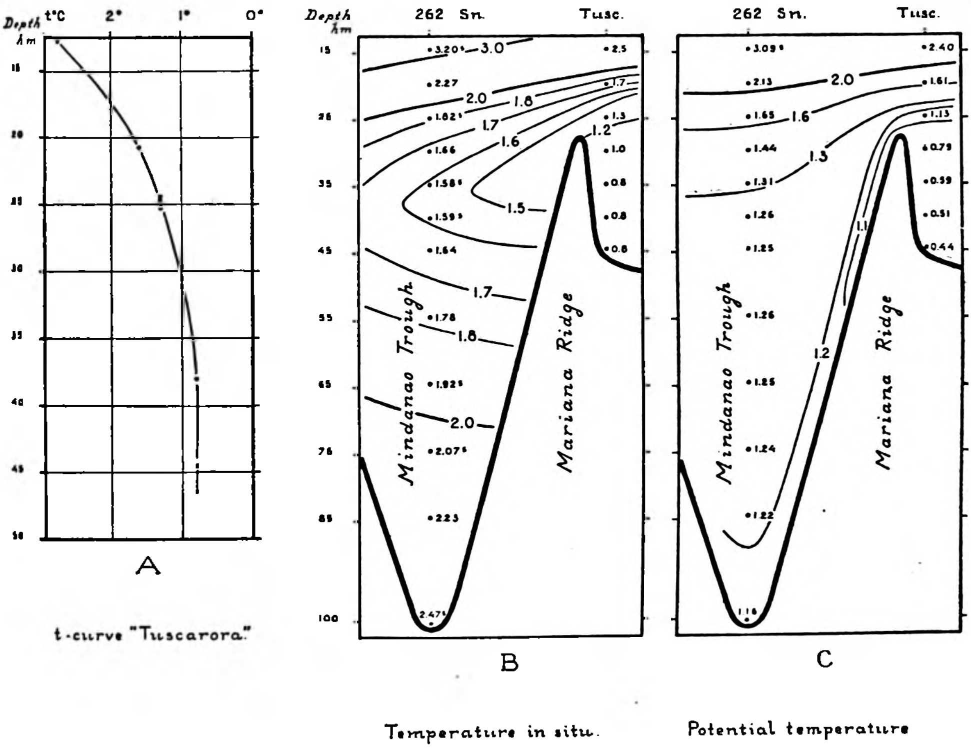

Fig. 4. Comparison of temperatures inside and outside the Mariana ridge.

warmer volume, whilst the bottom layers remain undisturbed. This representation is misleading as no consideration has been given to the increase of the temperature *in situ* in a descending current, owing to compression.

A better insight into the circulation may be derived from Fig. 4, C. The actual movement of the sill-current along the sea floor in the direction of station 262 is clearly shown by the trend of the potential isotherms.

The latter method will be followed below when examining the flow of the bottom water and the relation of the depth of the deepest entrance with the temperature of the abyssal layers in a partly closed basin.

When nothing is stated to the contrary the potential temperature means the temperature which a water-particle attains when it is raised adiabatically to the surface of the sea. The reduction of the temperature *in situ* to this level has been effected by using the tables A and B of Helland-Hansen and the annexed diagrams (Bibl. 15, p. 67). For the upper 1000 metres the corrections

derived from Schott's diagram (Bibl. 17) and Ekman's tables have been used (Bibl. 18). As the salinities deviated only slightly from 34.85 $^\circ/_{\circ\circ}$ and the differences had little effect on the value of the adiabatic variations, no salinity corrections have been applied.

After this degression on the use of the potential temperature we return to the approximate depth of the Mariana ridge and Fig. 4, C. When drawing the potential isotherms in the lowest strata we had to estimate the increase of the temperature along the great distance between the sill at about 30° N. and the position of station 262 at about 10° N.

Wüst mentions in the "Meteor"-publications (Bibl. 23, p. 36) an increase of the potential bottom temperature, in the western basin of the Atlantic Ocean, of about 0°.4 along a distance of about 45 degrees latitude. His vertical potential temperature section ("Beilage V") shows, near the floor in the Brasilian basin between 30° and 5° S., an increase of at most 0°.04. In the Banda sea we observed in the bottom-current (about 4500 metres) an increase of only a few hundredths of a degree Celsius along a distance of 4 to 8 degrees latitude. An increase of the bottom temperature of 0°.1 as assumed in Fig. 4, C, may therefore be not far from the real value; in 1500 and 2500 metres it amounts to 0°.7 and 0°.5 respectively [1]).

Regarding the reliability of the temperature values of the "Tuscarora" we must observe that, according to the latest Japanese observations (Bibl. 24) at station 424 (1926), the temperature *in situ* in 1500 metres is 2°.3 whilst 2°.5 has been derived from the "Tuscarora"-curve (Fig. 4, A), referring to about the same position. The estimation of the depth of the ridge will be only slightly influenced by an error of 0°.1 to 0°.2 C.

Having regard to what has been stated above we may conclude from the trend of the potential isotherms in Fig. 4, C, that the deepest passage across the Mariana ridge lies here at about 2750 metres.

It would have been more convincing if, in estimating this depth, the data from station 262 had been compared with those outside the ridge at the same latitude. The observations of bottom temperatures are, however, scarce here and seem to be less reliable. Schott and Schu (Bibl. 14, p. 15) mention a temperature *in situ* of 1°.8 at 3000 to 4000 metres at 15° N. and between 140° and 150° E. This value is much higher than those observed at station 262 (Table 1, p. 16), but also *inside* the ridge the "Challenger"-observations show too high values. Consequently these data could not be used for estimating the depth of the deepest passage in the Mariana ridge.

More to the south the oceanographic data outside the ridge are still more inadequate [2]). The southern part of the Mariana ridge, as shown on the present map, extends between New-Guinea and Palao and separates the Mariana basin from a basin to the south of the Caroline ridge. The bottom temperatures obtained here by the "Challenger", "Gazelle" and "Planet" are very different, so that a comparison of these diverging data with those from station 262 will not help us in estimating the depth of the southern part of the Mariana ridge.

However, according to Schott and Schu (Bibl. 14 "Tafel 10"), the temperature at 3000 metres is in these lower latitudes only 0°.1 or 0°.2 higher than at 30° N. Consequently the depth of the deepest passage need not be much greater than 2750 metres to cause a minimum potential temperature of 1°.16 as observed at station 262.

Summarizing, it seems to me that according to the available soundings and oceanographic considerations, the Mariana basin is isolated by a ridge, extending from New-Guinea to Japan, in which the passages are at all events not deeper than 2000 fathoms (3660 metres). This is in contradiction to the representation given by Groll (Bibl. 16) on which appear passages at 21°, 10° and 7°30′ N. of more than 4000 and 7000 metres.

We must, however, draw attention to the fact that according to the trend of the contour of 4500 metres to the east of Morotai, the Mindanao trough bends to the east, whilst some soundings to the north of New-Guinea at 132°30′ E. show a slight depression at over 4500 metres. This may point to the existence of a deeper passage running to the north of the Asia island parallel to the coast of New-Guinea [2]).

[1]) The Japanese observations (Bibl. 24, p.p. 58, 98 and 110) at the stations 424 (1926), 135 (1925), 326 (1926), (Bibl. 24, plate 74), and "Snellius"-station 262 show that the temperature *in situ* increases gradually at 1500 metres from 2°.3 to 3°.2. The position of the Japanese station 424 (1926) corresponds to the mean place of the "Tuscarora"-stations.

[2]) See appendix, p. 59.

As this supposition is based on inadequate material, the southern part of the Mariana ridge has been indicated on the present map by drawing a contour line of 4000 metres, connecting the Palao islands to New-Guinea. This is in correspondence with previous representations and with the summary above.

Further investigations concerning the possibility of a continuation of the Mindanao trough to the east may, however, give interesting results.

c. MOLUKKEN SEA.

The passages from the Pacific Ocean to the Archipelago may be divided into those to the north and south of the Talaud islands, leading to the Sangihe trough and the Molukken sea and those through the Halmahera sea to the Ceram sea.

The Molukken sea is limited on the west side by Celebes and the Sangihe islands, in the east by Obimajor, the Batjan group, Halmahera, Morotai and a ridge, extending from this island towards north-north-west. In the south this region is separated from the Banda sea by the Soela and Banggai groups whilst the parallel of 3°.5 N. may be considered as the northern limit.

By examining the contour of depth of 2500 metres the general appearance of the sea floor is better understood. The present depth chart shows a central ridge surrounded by deep basins and troughs.

On the east side lies the Morotai basin, the Ternate trough and the Batjan basin, on the south is situated the small Mangole basin and on the west side extends the narrow depression, connecting the Gorontalo basin to the Sangihe trough.

In general the depth contours run in a direction north — south, curving towards south-west near the entrance of the Gulf of Tomini and towards south-east in the vicinity of Batjan and Obimajor.

The central ridge, outlined by the depth contour of 2000 metres, lies between 3°30′ N. and 1° S. with an interruption at 0°30′ N. On the east side the islands Majoe and Tifore rise and to the east of these islands an isolated and elongated ridge appears, on which soundings in less than 2000 metres have been recorded.

Let us now consider the ridges, which separate the Molukken sea from the Pacific Ocean and the above mentioned basins and troughs mutually.

Morotai basin. In the north-eastern part of the Molukken sea a new basin could be outlined. This basin, called after the island "Morotai", has at a depth of 3000 metres an area of over 6500 square kilometres. The greatest depth recorded in it is 3890 metres, whilst a still deeper area may exist in the central part.

Detail chart 13 shows that a ridge extends from the island Morotai in a N.N.W.-ly direction as far as the Nenoesa islands. This ridge, limited by the contour line of 2500 metres and unknown hitherto, has been given the name of *Snellius ridge.* A single sounding in 1458 metres to the north of Morotai, occurring on Tydeman's chart (Bibl. 21), pointed to its existence. The smallest depth recorded on it, is 360 metres.

This ridge forms a hindrance to a free transport of bottom water to the deep Morotai basin. A great number of soundings, taken on the ridge, show a deepest passage (saddle-depth) of 2200 metres at about 3°20′ N. Let us consider whether this estimation is confirmed by oceanographic data.

The right part of Fig. 5 shows a vertical section across the sill between the Pacific Ocean and the Morotai basin (see Plate III) with the potential temperature distribution in centigrade and some of the salinity determinations (.63 = 34.63 $^{\circ}/_{\circ\circ}$).

In this figure, and also in the profiles discussed below, the abscissae denote the shortest distances between the stations, according to the scale at the top of the figure. The ordinates are the depths, in hectometres, not measured along the shortest distance, but showing the deepest connections between the stations. The month in which the observations have been carried out is indicated by a Roman figure next to the numbers of the stations.

In all profiles the vertical scale had to be exaggerated; consequently these figures give a totally

erroneous impression of the shape of the bottom-line. For this reason true-scale bottom contours have been drawn at the bottom of the successive profiles.

When we draw the isotherms for 1°.55 [1]) and 1°.6 C. outside the sill in correspondence to those of 1°.8 and 2°.0 C., it is evident, that a minimum potential temperature of 1.°55 C. cannot be the result of a transport of bottom water, crossing the Snellius ridge at a depth of 2200 metres as the detail chart 13 suggests. This depth must be about 2400 metres, a depth which would also explain a salinity of the abyssal waters of 34.65 °/₀₀. A close examination of the fair sheet shows, that a similar passage may exist at about 3° N. So the sill has been drawn at a depth of 2400 metres in Fig. 5.

We must however consider a *second* connection of the Morotai basin with the Pacific Ocean probably at about a similar depth. Between the Talaud islands and the Snellius ridge a very narrow trench extends in a direction north — south from 5°30′ to 3°30′ N. The existence of this trough, called the *Talaud trough,* is concluded from some deep soundings along cross-sections, lying at a great

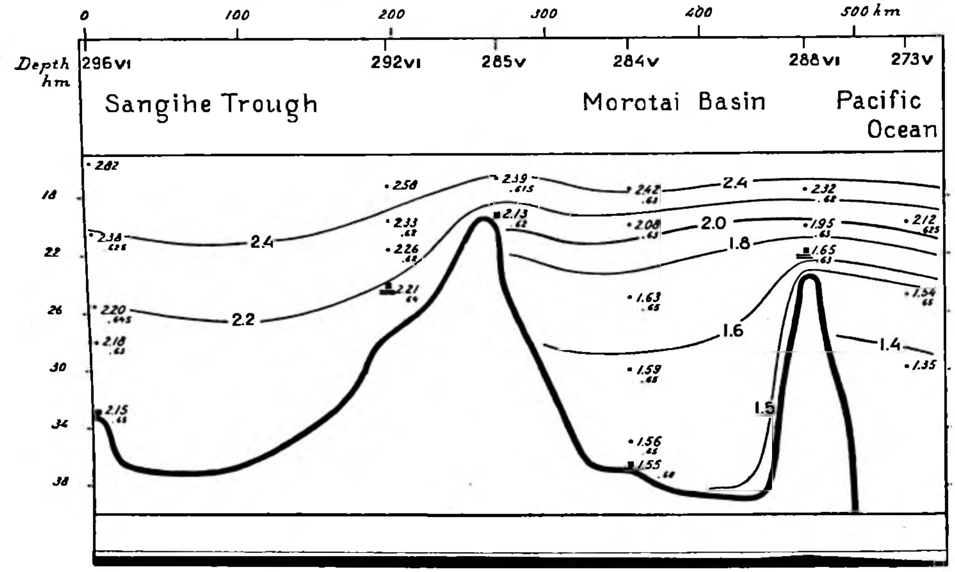

Fig. 5. Section from Pacific Ocean to Sangihe trough along Morotai basin. Potential temperature and salinity.

distance from each other. The maximum depth recorded in it is 3450 metres, whilst a sill in 3130 metres at 5°12′ N. and 127°03′ E. separates it from the Pacific Ocean.

It depends on the depth of the inner sill, lying between the southern part of the Talaud trough and the Morotai basin, whether the minimum potential temperature of 1°.55 C. must not be attributed to an indirect transport of Pacific water along this *second* passage and crossing this inner sill.

To our regret soundings are lacking on this sill. As the potential temperature of 1°.55 C. has been observed just outside the Talaud trough at 2450 metres, the passage between Talaud trough and Morotai basin will not be much deeper, for in that case lower temperatures would have been observed near the sea floor in the latter basin. Consequently the depth contour of 2500 metres has been drawn closed on detail chart 13, on both sides of the sill in this passage between Snellius ridge and the ridge extending from the Talaud islands south-eastwards.

It should be noted that the value observed for the salinity near the floor of the Morotai basin (station 284) is much higher than those observed in the abyssal layers lying above. (34.68 °/₀₀ against 34.65 °/₀₀). This high value may be due to an error in the titrations (34.67 and 34.69) as no such salinities occur at 2300 to 2500 metres at the stations 270, 271, 272 and 273 in the vicinity of the entrances. (see Plate III).

[1]) In Fig. 5 has been printed 1.5 instead of 1.55.

Summarizing we may conclude as follows:

1. *An indirect connection between the Morotai basin and the Pacific Ocean is possible across the sill lying between the Talaud trough and the Morotai basin at 3°25′ N. and 127°35′ E. at a depth of about 2450 metres.*
2. *This passage is not much deeper than 2450 metres.*
3. *If this passage is shallower the minimum potential temperature must be attributed to a direct flow from the Pacific Ocean, crossing the Snellius ridge at about 3° N. at a depth of 2400 metres.*

Ternate trough. From the Morotai basin a narrow depression runs towards the south between the ridge to the east of the islands Majoe and Tifore and the row of smaller islands off the coast of

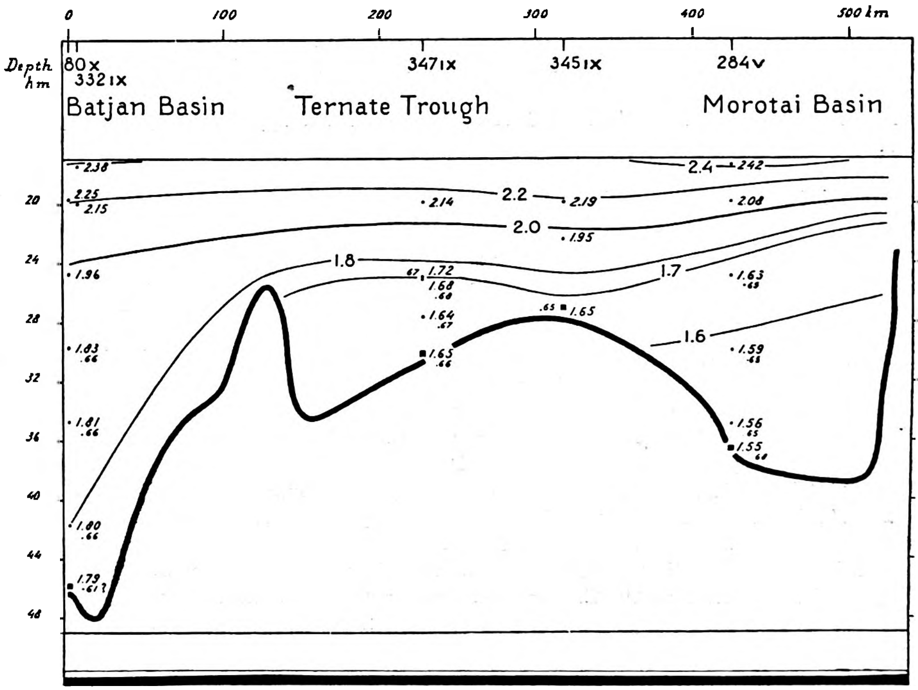

Fig. 6. Section from Morotai basin to Batjan basin along Ternate trough. Potential temperature and salinity.

Halmahera. The deepest southern part of this depression, limited by the contour of depth of 3000 metres, has been called Ternate trough after the island of that name. The area of this trough at a depth of 3000 metres amounts to over 1000 square kilometres; the greatest depth of 3450 metres has been recorded in the southern part. A sill between the Morotai basin and the Ternate trough lies, according to the "Snellius"-soundings, 2710 metres beneath the surface at 1°46′ N. and 127°12′ E.

Fig. 6 shows the potential temperature distribution with some salinity observations in a longitudinal section from Morotai basin to Batjan basin (see Plate III). The temperature observed near the sill at station 345 agrees with the minimum potential temperature in the trough at station 347, so that the saddle-depth of 2710 metres has been maintained.

Batjan basin. South of the equator the elongated depression on the east side of the central ridge widens into the Batjan basin, which has an area at a depth of 3000 metres of nearly 7000 square kilometres. The maximum depth hitherto recorded here is 4810 metres.

A sill between Ternate trough and Batjan basin is estimated, according to the soundings, at 2800 metres beneath the surface at 0°05′ S. and 126°42′ E. If, however, the Batjan basin stood in

direct horizontal connection with the Ternate trough at this depth, the minimum potential temperature in the first basin would be lower than 1°.79 C. according to Fig. 6. In this figure the isotherms for 1°.8 and 1°.7 C., north of the sill (in the figure to the right) have been drawn parallel to that for 2°.0 C. *Probably a shallower sill exists at approximately 2550 metres beneath the surface at about 0°15' N.* The bottom-line in Fig. 6 has been drawn in correspondence with this assumption.

The salinity 34.61 $^{\circ}/_{\circ\circ}$ near the sea floor at station 80 must be regarded as an error in the titrations or a bad working of the bottom water sampler. The amount of 34.66 $^{\circ}/_{\circ\circ}$ in the abyssal layers originates, according to Fig. 6 from a depth of 2400 metres at station 347.

Mangole basin. The small basin, lying between the central ridge and the island Mangole, has been called Mangole basin. It is separated from the Batjan basin by a sill at a depth of about 2710 metres (see Fig. 7, Plate III and detail chart 11) at about 1°28' S. and 126°38' E. A small number of soundings show a maximum depth of 3510 metres; future investigations may show still greater depths more to the west. The outline, drawn on the depth chart, is somewhat hypothetical.

The area of this basin at a depth of 3000 metres amounts to approximately 1900 square kilometres.

Gorontalo basin. The floor in the extreme southern part of the Molukken sea, where a rise separates the Mangole basin from the Gorontalo basin, is rather irregular. As the soundings are scarce, the greatest depth of the passage connecting the two basins cannot be fixed with certainty. According to the soundings, this depth may be estimated approximately at 2700 metres.

The minimum potential temperature observed in the Gorontalo basin is 1°.95 C. The potential isotherm for 1°.95 C. in Fig. 7, which has been drawn parallel to that for 2°.0 C., *shows that the depth of 2700 metres, as derived from the scanty number of soundings, will not be far from the truth.*

This is not in accordance with Tydeman's chart, which shows a ridge at less than 2000 metres, extending between the Talaud islands and the eastern tongue of the island Celebes and the Banggai Archipelago. There is, however, some indication, that a similar ridge exists, be it at greater depth than supposed by Tydeman. From the island Peleng extends a shallower spur north-eastwards at about 0°44' S. and 124°19' E., which according to a previous sounding in 2460 metres (0°40' S. and 124°37' E.) and the general trend of the isobaths, may be connected with the ridge extending towards south-south-west from the island Tifore.

This ridge has been indicated in Fig. 7 at about 660 kilometres from station 296. From the course of the potential isotherm for 1°.95 C. it appears however, that there must be a passage through this ridge of at least 2800 metres depth. The depth contour of 2500 metres has therefore been drawn on the present map in accordance to these considerations.

The Gorontalo basin, in which a maximum depth of 4180 metres has been recorded, has an area at a depth of 3000 metres of approximately 14000 square kilometres. From this basin a narrow depression, between the central ridge and Celebes, leads to the Sangihe trough, running parallel to the row of islands lying on the Sangihe ridge.

d. SANGIHE TROUGH. (Detail chart 15).

The Sangihe trough is limited on the east and west side by the row of islands, lying on the Talaud ridge, and those on the ridge which connects the island Mindanao with Celebes. The elevations of Mindanao form a continuation of both ridges.

The Gulf of Davao forms the northern part of the trough; two tongues, which extend south-east and south, lead to the Morotai and the Gorontalo basin. The area of the trough at a depth of 3000 metres amounts to over 10.000 square kilometres. The greatest depth recorded in it is 3820 metres, south-west of the island Miangas at 5°25' N. and 126°22' E.

Detail chart 15 shows the passages from the Pacific Ocean to the Sangihe trough. From Cape San Agustin a narrow ridge extends south-south-east to about 5°20' N., limited by the depth contour of 1500 metres, which connects the island Miangas with Mindanao.

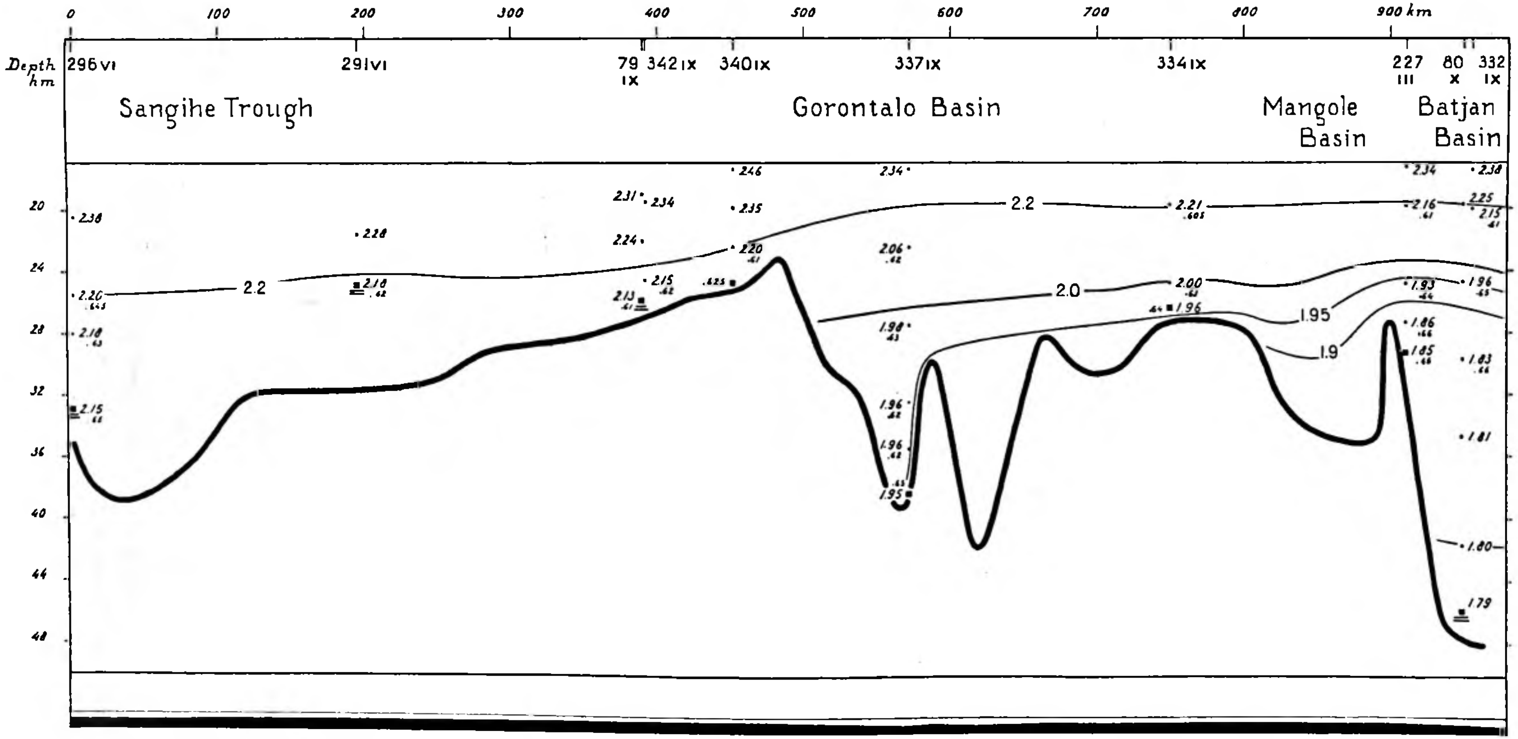

Fig. 7. Section from Batjan basin to Sangihe trough along Mangole basin and Gorontalo basin. Potential temperature and salinity.

On the northern part a small shoal has been observed at about 6° N., on which soundings of less than 200 metres have been recorded. Between this shoal and the Cape the saddle-depth amounts to about 500 metres, whilst north of Miangas the passage is at the most 1400 metres deep.

Between Miangas and Karakelong, the principal island of the Talaud group, lies the deepest passage across the Talaud ridge, which connects the Pacific Ocean with the Sangihe trough. If the sounding of 1940 metres, at 5°08′ N. and 126°41′ E., must be regarded as belonging to the Pacific-slope of the sill, the depth of the passage is not more than 1780 metres, according to the representation of the fair sheet. The potential temperature and salinity distribution should be examined for further light on this question.

Fig. 8 shows a section along the stations 265, 294 and 296 (see Plate III). The lowest potential temperature in the Sangihe trough is 2°.15 C. at station 296. A similar temperature cannot be caused by a direct transport from the Pacific Ocean at a depth of 1780 metres. This depth should be about 2050 metres, according to the trend of the isotherms in Fig. 8 .This figure shows a salinity of 34.64 and 34.59 °/$_{oo}$ at about 2200 and 1700 metres at station 265. At station 266, however, a salinity has been observed at a depth of 2500 to 2000 metres of 34.64 °/$_{oo}$, which from the latter level rapidly decreases with decreasing depth. As both stations lie very close together, we may conclude, that at station 265 also a salinity of 34.64 °/$_{oo}$ occurs at about 2000 metres and that a potential temperature of 2°.15 C. of the sill-current will be accompanied by a salinity of 34.64 °/$_{oo}$; at the bottom layer of the Sangihe trough it amounts to 34.65 °/$_{oo}$.

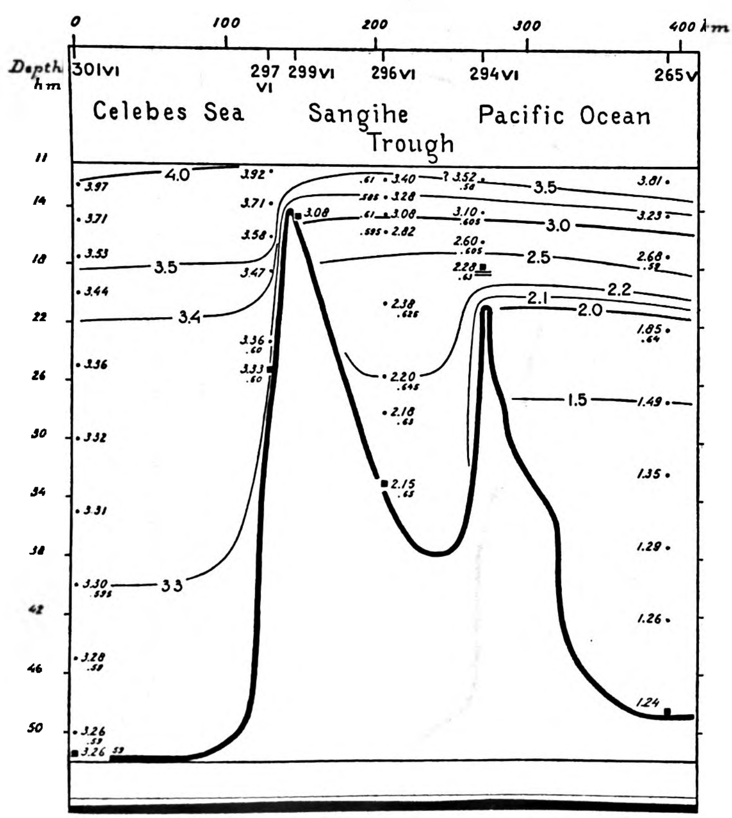

Fig. 8. Section from Pacific Ocean to Celebes sea along Sangihe trough. Potential temperature and salinity.

Before accepting the saddle-depth of 2050 metres and the renewal of the Sangihe trough by a direct transport from the ocean, across the sill between Miangas and Karakelong, we must ascertain whether a minimum potential temperature of 2°.15 C. and a salinity of 34.65 °/$_{oo}$ may not be explained by assuming a transport from the Morotai or Gorontalo basin.

The first thing to be considered is the connection between the Morotai basin and the Sangihe trough. The soundings on the depth chart and detail chart 13 show on the central ridge of the Molukken sea, to the south of the Talaud islands, depths of over 2000 metres. Following the small number of soundings at our disposal we suspected here at 3°04′

N. and 127°06′ E. a sill at about 2200 to 2300 metres. This would mean a deeper passage than the one mentioned above across the Talaud ridge at about 2050 metres to the north of Karakelong.

A transport from the Morotai basin at a depth of 2200 to 2300 metres would however, according to Fig. 5 (see p. 20), cause a lower minimum potential temperature (1°.8 C.) than has been observed (2°.15 C.). The same figure shows that the actual minimum corresponds to a saddle-depth of 1930 metres, but then this minimum would be accompanied by a salinity of 34.62 ‰ instead of 34.65 ‰. Consequently we may presume that *the bottom layers in the Sangihe trough do not originate from the Morotai basin* and that the saddle-depth between Morotai basin and Sangihe trough is probably less than 1930 metres. Consequently *the central ridge of the Molukken sea is connected with the Talaud ridge by the depth contour of 2000 metres.* The single sounding in 2409 metres at 3°08′ N. and 127°00′ E. is an earlier wire sounding and may be regarded as too high.

Secondly we must ascertain whether the bottom water of the Sangihe trough does not originate from the Gorontalo basin. We have seen above that a narrow depression connects the two basins. In this depression a sill is supposed to exist, according to the soundings, at about 2500 metres, to the east of Kema at 1°20′ N. and 125°28′ E.

Fig. 7 (see p. 23), however, shows that a similar saddle-depth between the stations 337 and 340 would cause a bottom temperature in the Sangihe trough of about 2°.05 C. instead of 2°.15 C. To explain the latter temperature a saddle-depth of 2300 metres as indicated in Fig. 7 would be sufficient. But then this temperature would be accompanied by a salinity of about 34.61 ‰ instead of 34.65 ‰. Consequently we may conclude *that the bottom layers in the Sangihe trough are not renewed by water entering from the Gorontalo basin* and that the sill may be shallower than 2300 metres. *In any case the 2500-metre line must be drawn closed on either side of the sill* lying to the south-east of Kema.

Summarizing it appears, that the bottom water of the Sangihe trough is renewed by a direct transport from the Pacific Ocean across the sill north of the Talaud Is. at approximately 2050 metres, and not by any indirect transport along the Morotai or Gorontalo basin.

This conclusion is principally based on the salinity determinations and the consideration, that the salinity of the sill-stream, entering the trough from the Pacific Ocean, in combination with a potential temperature of 2°.15 C., comes *nearest to that* of the abyssal waters inside. (Figs. 5, 7 and 8, p. 20, 23 and 24).

e. THE GULF OF TOMINI.

This gulf, forming the western extension of the Molukken sea, is limited by the north-eastern and eastern tongue of Celebes. Owing to lack of time this region has not been investigated by the Snellius-expedition. Captain S. P. L'Honoré Naber has, however, carried out a great number of wire soundings here on board H.M.S. "Bali". From these data it appears, that the depth decreases gradually from the Gorontalo basin towards the west. The floor of the inner-part of the gulf is a rather flat plain at a depth of about 2000 metres. Between the Togian group and Celebes lies an isolated small basin, in which the greatest depth has been recorded at about 1800 metres. The entrance of this basin is supposed to be a little more than 1000 metres below the surface of the sea.

f. CELEBES SEA.

The Celebes sea is limited on the north and south by the Philippine islands and Celebes, on the east and west by the Sangihe ridge and Borneo.

The sounding tracks of the "Snellius" lie rather wide apart, especially in the northern and central part. As the floor appears to be rather flat, the scantiness of soundings is here of less importance. Moreover the soundings in the northern part derived from the charts of the "U.S. Coast and Geodetic Survey" form a welcome supplement. They correspond very well to the "Snellius"-results.

The floor of the Celebes sea is fairly level and rises gradually at the sides. The present chart

shows some steeper sloping portions in the south-east and south-west, where the 5000-metre line comes very near to the coast of the north-eastern tongue of Celebes and the shore-line of Maratoea island and the Moearas reef.

In Fig. 9 the section O—P represents the true-scale bottom contour in the south-eastern part of the Celebes sea. (see Plate III). The angle of sloping of the island Manado Toea of about 27° is continued beneath the sea level for a short distance. After a slight increase of depth and a steeper portion with a dip of about 12° follows a comparatively flat sea floor.

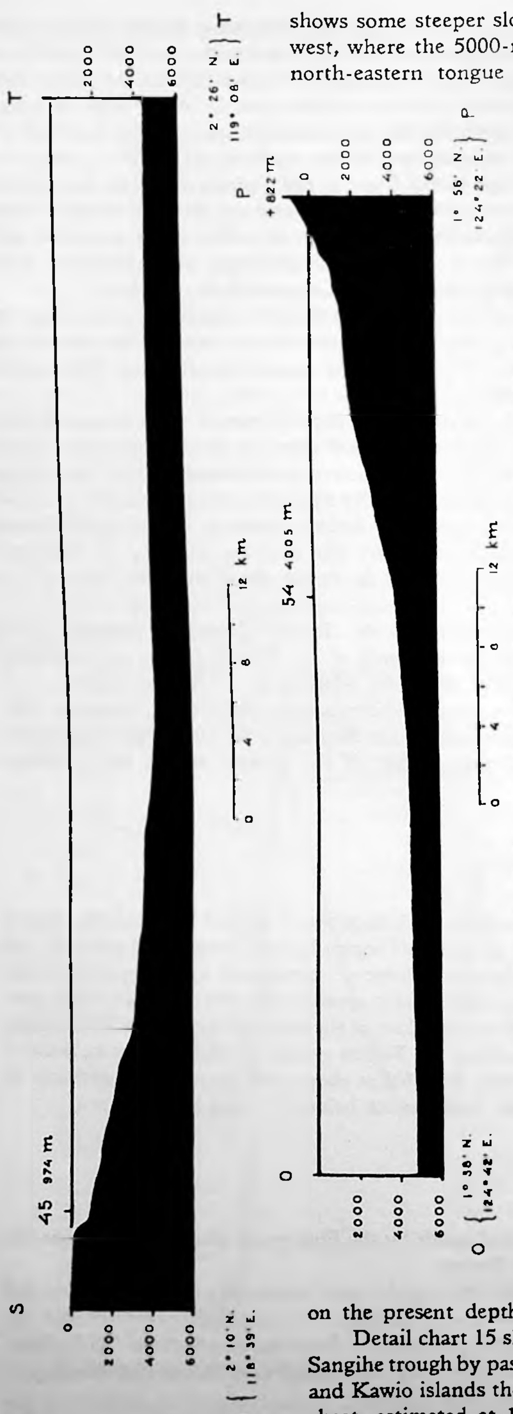

Fig. 9. True-scale bottom contours in the south-eastern and south-western part of the Celebes sea.

Section S—T in the same figure shows the bottom contour in the south-western part of the Celebes sea off the east coast of the island Maratoea. (see Plate III). From the edge of the reef the bottom slopes downwards at an angle of about 45° at first; later the gradient rapidly decreases to about 12°. The eastern part of the section shows an even floor at about 4000 metres.

The area of the Celebes basin at a depth of 4000 metres amounts to over 260.000 square kilometres. In the southern and north-eastern portion trough-shaped depressions occur, outlined by the depth contour of 5500 metres, running parallel to the north coast of Celebes and to the south-west coast of Mindanao. At 5°50′ N. and 123°40′ E. the greatest depth has been recorded, according to American charts, of 6220 metres.

At about 4° N. and 124°10′ E. a submarine volcano, of which the existence is rather doubtful, has been plotted on the chart. Lack of time prevented further examination. The small island of "Hooiberg" at 4°07′ N. and 125°07′ E. mentioned on p. 425 of the "Zeemansgids voor Nederlandsch Oost-Indië, Deel II, 1931" does not exist, according to the latest investigations of one of the Netherlands surveying ships; consequently it has not been plotted on the present depth charts.

Detail chart 15 shows that the Celebes sea is connected with the Sangihe trough by passages in the Sangihe ridge. Between Sarangani and Kawio islands the depth of the entrance is, according to the fair sheet, estimated at 1570 metres at 5°13′ N. and 125°33′ E.

Detail chart 3 shows the connection with the Molukken sea. The passages north and south of the island Siaoe and that south of Biaro are the most important here. To the north of Siaoe a single previous sounding of 1375 metres is available, whilst to the south of this island, in Siaoe strait, the depth of the entrance may be estimated at 1530 metres. In the southern part of the entrance between Biaro and Celebes (Biaro strait) a depth of about 1400 metres has been recorded on the sill.

Tydeman (Bibl. 8) concludes from some temperature observations that the passages to the Celebes sea between the islands, lying on the Sangihe ridge, are not deeper than 1400 metres and Weber (Bibl. 7, p. 5) estimates the greatest depth at less than 1300 metres, according to the results of the Siboga-expedition. A similar depth has been suggested by Krümmel in 1882 (Bibl. 1).

Let us now consider whether the observations of temperature and salinity, carried out during the Snellius-expedition inside and outside the Celebes sea, correspond to the results of the echo-soundings or the surmises of previous explorers.

Fig. 8 (see p. 24) shows the vertical distribution of potential temperature and some salinity determinations in a section through the passage south of the Sarangani islands (Kawio strait) along the stations 296, 299, 297 and 301 (see Plate III). According to the echo-soundings the saddle-depth in this passage had been estimated at 1570 metres. From the potential isotherms for 3°.3 and 3°.0 C., which have been drawn in Fig. 8 in correspondence to that of 3°.5 C. it appears however, that *in a similar depth* the sill-current would cause a potential bottom temperature in the Celebes sea lower than 3°.26 C. To *this* temperature corresponds a saddle-depth of 1400 metres at most, at 5°10′ N. and 125°30′ E.

It may be possible that the coldest (and heaviest) water enters the Celebes sea along one of the other passages mentioned. The vertical section of Fig. 10 may throw some light on this question (see Plate III).

We will first take the passage between Celebes and Biaro (Biaro strait, detail chart 3). In the centre of this entrance the sea floor rises to 540 metres below the surface. Soundings are scarce between this rise and the island of Biaro, so that we are not certain of the saddle-depth, which has been estimated at 1400 metres.

The potential bottom temperature 3°.29 C. at station 53, Fig. 10, is a little higher than that at station 301, to the west of Kawio strait (Fig. 8, p. 24). If this temperature is caused by a transport of bottom water through Biaro strait, the saddle-depth must be, according to the course of the isotherms in Fig. 10, about 1400 metres. This would be in agreement with the estimation based on soundings. But then this second entrance could also provide for the renewal of the bottom layers in the Celebes sea.

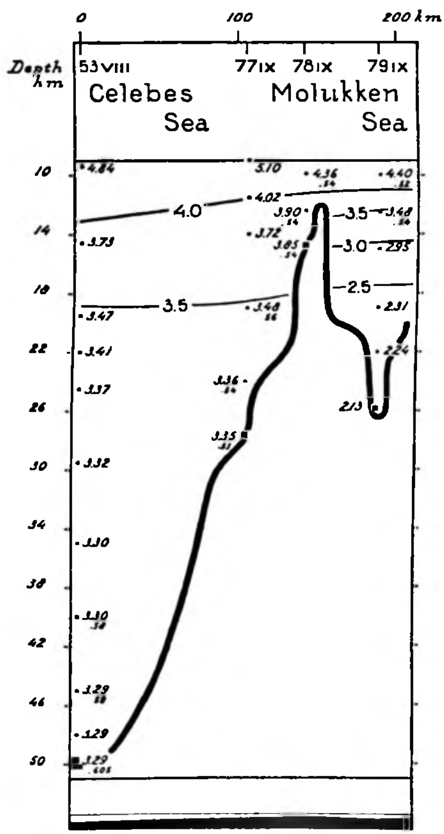

Fig. 10. Biaro strait. Section from Molukken sea to Celebes sea. Potential temperature and salinity.

There are however two facts, which do not agree with this.

1°. West of Kawio strait the potential bottom temperature is lower than that west of Biaro strait. This points to a bottom-flow in the Celebes sea starting from Kawio strait and not from Biaro strait.

2°. Fig. 8 (see p. 24) shows a salinity of 34.59 ‰ near the floor at station 301, which has been

determined also in the Sangihe trough at the depth of the sill. According to Fig. 10 a sill-current running through Biaro strait at a depth of 1400 metres is characterized by a potential temperature of 3°.29 C. and a salinity of 34.54 ‰. This is not in agreement with what has been observed near the floor at station 53, where 34.60 ‰ was determined.

An estimation of 1400 metres as the greatest depth in Biaro strait must therefore be regarded as too high. With a view to the temperatures observed on the inner side of the sill at station 78, the saddle-depth has been estimated at 1200 metres. The passage between the central rise in the strait and the island Biaro will not be deeper either.

When dealing with the general circulation of the water layers a closer examination of *all* data may show whether the resultant sill-current in Biaro strait is not directed to the Molukken sea.

Finally we come to Siaoe strait. Here we observed at station 289:

Depth in metres	Pot. temp. °C.	Salinity ‰
1360	3°.54	34.59
1540	3°.41[5]	34.59

Station 289 lies on the innermost edge of the sill in Siaoe strait. From the fact, that the temperature is lower and the salinity higher than at station 78 (Fig. 10) we may conclude that there is a sill-current, entering the Celebes sea. This sill probably lies at 2°33′ N. and 125°39′ E. On account of the temperatures observed at station 289 in 1360 and 1540 metres, we may estimate the depth of this sill at about 1300 metres, i.e. a hundred metres more than in Biaro strait. Probably the sill-current in this passage does not attain the deepest layers, as in that case the potential temperature in 1360 and 1540 metres at station 289 should be lower.

The above mentioned facts make it highly probable *that the deepest entrance to the Celebes sea occurs in Kawio strait. In this case the saddle-depth must be about 1400 metres (Fig. 8, p. 24). In Biaro and Siaoe strait the greatest depth does not exceed 1200 and 1300 metres respectively.*

The comparison of the properties of the sea water inside and outside the Celebes sea shows at all events *that Celebes must be connected with Mindanao by a submarine ridge limited by the contour of depth of 1500 metres.*

g. MAKASSAR STRAIT. (Detail chart 1).

In the most important outlet of the Celebes sea, leading to Makassar strait, the bottom configuration is rather complicated. Off Tg. Mangkalihat (Borneo) the contour of 1000 metres extends far south-eastward. Between this *Tandjong* (Point) and the Celebes coast the sea floor rises to a depth of about 1000 metres. Farther eastward two separate depressions occur at depths of over 3000 metres; the outline of the most easterly and elongated one is rather uncertain.

Where the entrance to Makassar strait is narrowest between the 2000-metre lines, a sill appears at about 0°20′ N. at over 2300 metres. Tydeman (Bibl. 21) mentions a depth of about 2500 to 3000 metres. From here an elongated depression, of which the area at 2000 metres is about 55.000 square kilometres, extends southward as far as the south-west point of Celebes.

To the south-west of Cape William a narrow passage leads towards the southern part of the trough at a depth of about 2080 metres. Here the shore-bank of Borneo comes very close to the Celebes coast. This Borneo-shelf, overspread with small islands and barrier-reefs, forms the extreme south-eastern part of the Asiatic continental-shelf.

According to previous wire soundings the greatest depth in the northern and southern part is 2540 and 2457 metres respectively. A previous wire sounding of 2717 metres at 1°44′ S. and 117°45′ E. is regarded as erroneous, though it has been maintained on the depth charts.

h. SULU SEA.

The Sulu sea lies between Borneo and the Philippine islands. The contours of depth drawn on the present maps, are principally based on the soundings of the "U.S. Coast and Geodetic Survey". These are in agreement with the echo-soundings of the Snellius-expedition.

Parallel to the island Palawan and the Sulu Archipelago a ridge extends between Borneo and Celebes with many islands and reefs, which divides the Sulu sea into two parts of which the south-eastern is deepest.

Here we find the deep Sulu basin with an area at 4000 metres of over 46.000 square kilometres. On the eastern side of this basin lies a trough-shaped depression, outlined by the contour of depth of 4500 metres; consequently the slope is steepest here and the bottom shoals towards north-west. According to the American soundings the greatest depth has been recorded as 5580 metres at 8°50′ N. and 121°50′ E.

In the north-western part the sea floor sinks to a depth of a little more than 2000 metres and does not show sharp contrasts between rises and depressions.

Of the various passages which lead from the Celebes sea into the Sulu sea the Sibutu strait is the most important.

Basilan strait has a depth of less than 100 metres whilst the various passages through the Sulu Archipelago have a sill-depth which does not exceed 200 metres. According to Tydeman's detail chart published in the "Siboga"-work (Bibl. 8) the deepest passage here has a sill of about 155 metres north of the island Jolo.

Detail chart 2 shows the bottom configuration in Sibutu strait based on the "Snellius"-soundings, amplified by data from American charts. To give a clear view the depth contours for 250, 275 and 300 metres have been plotted next to the ordinary ones.

From the island Sibutu a wide shore platform extends towards the east whilst in the eastern part of the strait the 200-metre line lies close to the shore of the islands Simunul and Manukmanka.

Between these two shelves the northern and southern depth contours of 275 metres come very near to each other. Between them the sill-depth may be estimated at 270 metres.

To the south of the strait the slope of the floor is rather steep, to the north the passage widens into a small basin with varying depths of 200 to 600 metres, closed on the north by a submarine ridge on which the Pearl bank lies. When crossing this ridge the lowest depth sounded by the "Snellius" was 240 metres, east of Pearl bank. To the west of this bank however the passage may be much deeper and a comparison of the properties of the sea water in the Celebes sea and in the Sulu sea may give an indication of the saddle-depth of the Pearl bank ridge. Tydeman (Bibl. 21) surmises that along this passage the bottom layers in the Sulu sea will be renewed by a transport from the Celebes sea and estimates the sill-depth at 380 metres.

Fig. 11 shows the potential temperature distribution in a vertical section along the stations 67, 68, 69, 71 and 73 (see Plate III). At station 67 in the Sulu sea a lowest potential temperature of 9°.89 C. has been observed at 1500 and 1750 metres; further to the north a bottom temperature of 9°.85 C. occurs at station 64 and 65. Taking into account the large temperature variations which may occur in the Celebes sea between a level of 200 and 300 metres outside the sill of Sibutu strait, a temperature of 9°.89 C. in the small basin to the north of the strait may be caused by a sill-current at a depth of 270 metres, entering from the Celebes sea.

We regret that in this small basin temperature data at station 69 are available only to a depth of 300 metres, but these observations and the trend of the isotherms show that the depth of the Pearl bank ridge should be much deeper than 240 metres to allow a transport of bottom water at a potential temperature corresponding to that of the bottom water in the Sulu sea.

Owing to the lack of deeper temperature data at station 69, we have relied on other properties of the sea water and have drawn sections for the distribution of salinity and oxygen. As these sections, however, showed that a sill-current running from the Celebes sea towards the Sulu sea is not likely, in Fig. 12 we have given only the southern part of the sections to prove this fact.

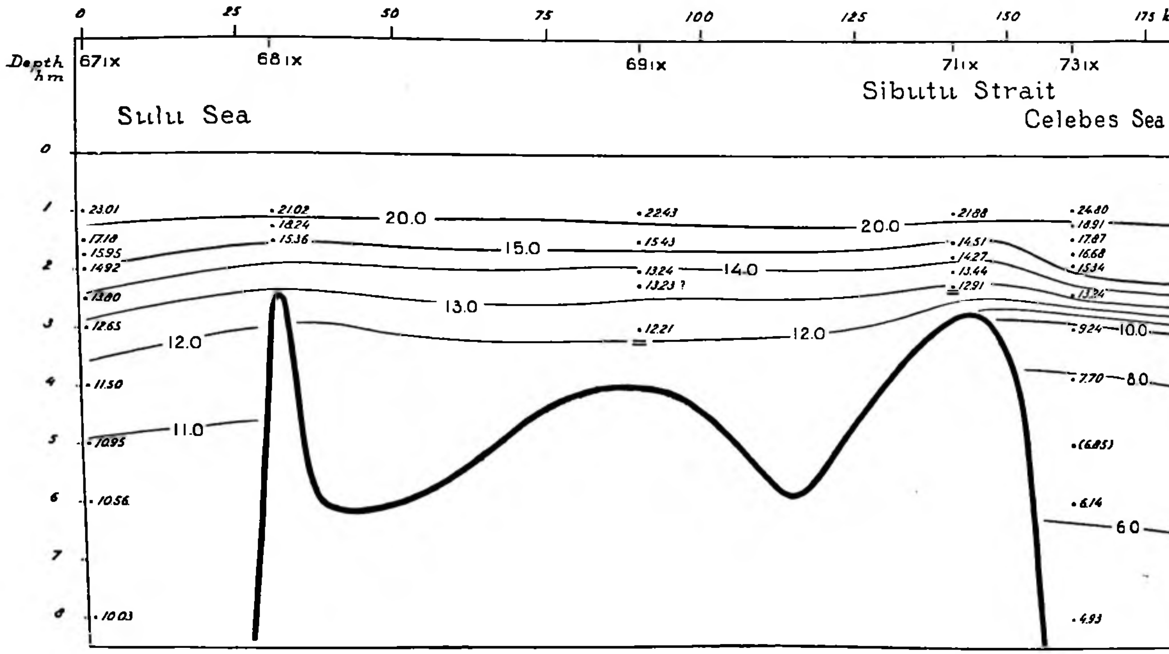

Fig. 11. Deepest passage between Celebes sea and Sulu sea. Vertical section potential temperature.

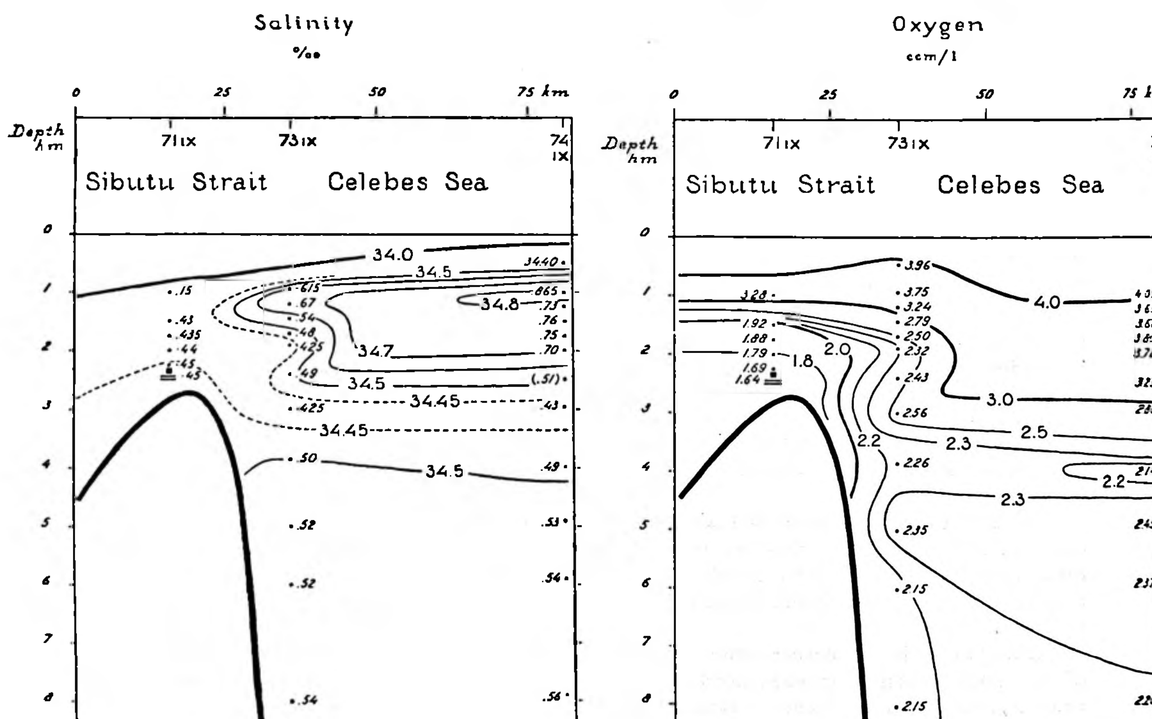

Fig. 12. Salinity and oxygen distribution at the entrance of the deepest passage leading from Celebes sea to Sulu sea.

In Sibutu strait low salinities have been observed, whilst a maximum of over 34.80 ‰ occurs in the Celebes sea between 100 and 200 metres. This saline layer ends abruptly outside Sibutu strait and does not point to an inward flow. From the minimum at 300 metres, corresponding to the salinity above the sill, we may rather assume a flow in the opposite direction towards the Celebes sea.

The amount of oxygen at station 71 is less than 2.00 cc per liter below a depth of 150 metres, an amount which does not occur in the Celebes sea layers. Here a minimum value has been observed at about 400 metres.

Both representations, which refer to the month of September[1]) are in agreement with each other and point to an outward flow of water from the Sulu sea. But in this case nothing definite can be ascertained about the depth of the Pearl bank ridge from a comparison of the properties of the sea water on both sides of the passage. According to the trend of the potential isotherm for 12° C. in Fig. 11 on both sides of the sill we may only conclude, that the saddle-depth probably is not less than 300 metres.

If the bottom water in the Sulu sea is not renewed by water from the Celebes sea along Sibutu strait there must be another deeper passage for this purpose. This passage probably lies west of the Philippine islands Panay and Mindoro (Apo East Passage), connecting the China sea with the Sulu sea. Chart 4200 of the "U.S. Coast and Geodetic Survey" shows a sill in this passage south of Mindoro near Domingo Shoal at about 400 metres. According to the temperature observations of the "Challenger" and the "Vitiaz" in this region a minimum temperature as observed by us in the Sulu sea could be explained by a transport of bottom water across this sill.

The direct connection with the Pacific Ocean across the Philippines is in the first part very deep; outside Surigao strait however the depth does not exceed 50 metres.

This subject will be treated more thoroughly in another chapter when dealing with the flow of the bottom water. *For the present we may conclude that the saddle-depth in Sibutu strait is 270 metres and that the inner passage off Pearl bank is not shallower than 300 metres.*

i. HALMAHERA SEA.

The Halmahera sea is bounded on the west and east by the island Halmahera and the shelf of New-Guinea. On the north side this sea is separated from the Pacific Ocean by a submarine ridge, connecting Halmahera with the island Waigeo. A wide rise of the sea bottom between the southern tongue of Halmahera and the shelf of New-Guinea separates this inland sea from the Ceram sea.

The shallow entrance in the northern ridge is of little importance as far as concerns the transport of bottom water from the Pacific Ocean to the Archipelago. On the single track of the ship a lowest depth of 430 metres has been recorded at 0°41′ N. and 129°35′ E. It may however be possible, that east and west of this position deeper passages occur in the narrow channels between the islands and reefs.

A second narrow ridge, extending from the eastern tongue of Halmahera in the direction of the island Gébé, divides the Halmahera sea into two parts. The saddle-depth of this second ridge amounts to about 940 metres at 0°06′ N. and 129°08′ E., according to the "Snellius"-soundings. Tydeman (Bibl. 21) mentions a second entrance of about equal depth, based on a wire sounding of 845 metres east of the island Gébé.

Southward of this second ridge lies the Halmahera basin, the area of which at 1000 metres is over 15.000 square kilometres. The greatest depth recorded is 2039 metres, according to a previous sounding. The outline of the 2000-metre area, based on this sounding and the assumption of a deeper area in the centre of the basin, is consequently somewhat hypothetical. Time did not permit a closer examination of this basin.

The southern bar, overspread with many small islands and reefs, is intersected by two

[1]) A great number of wind observations from Netherlands ships give a southerly direction for the general air circulation for September in this region.

deep and narrow depressions, running from the Molukken sea through Obi strait and from the Ceram sea north-eastwards between the islands Misool and Obimajor as far as the island of Kofiau. Moreover the bottom configuration is very irregular and the available soundings are scarce. In view of this it is not possible to fix a definite deepest passage connecting the Ceram sea with the Halmahera sea. According to the soundings a passage may exist west of the island Boo of about 600 to 700 metres.

A temperature profile (Fig. 13, Plate III) from the Pacific Ocean to the Ceram sea, crossing the Halmahera sea may give more light on this matter. In this figure, which shows the vertical potential temperature distribution, some salinity data have been inserted also.

In the Halmahera basin a minimum potential temperature of 7°.55 C. and a salinity of 34.60 °/₀₀ have been observed at station 353 near the bottom which may be caused by a transport of bottom water, either across the northern or southern sill.

If the saddle-depth of the northern sill between stations 351 and 352 was really 430 metres,

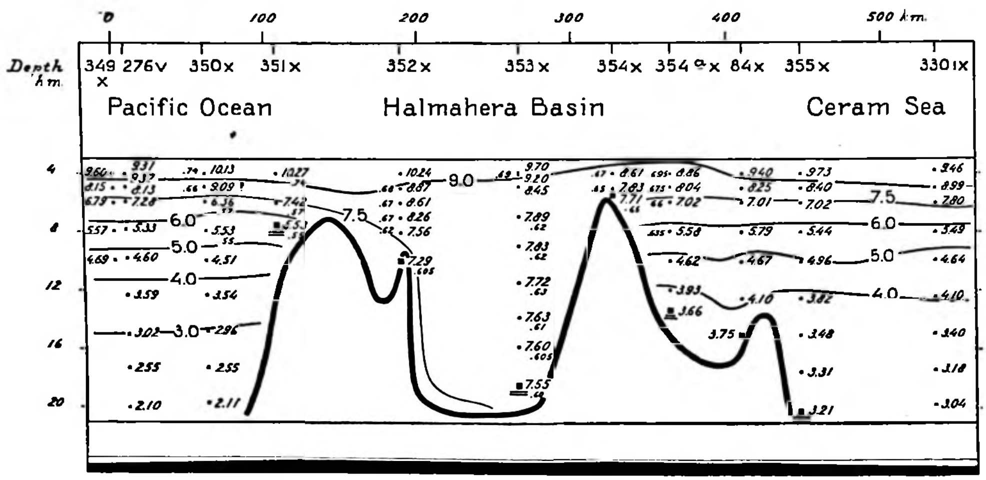

Fig. 13. Section from Pacific Ocean to Ceram sea, crossing Halmahera sea. Potential temperature and salinity.

the lowest potential temperature, observed at station 352 in the small basin between the northern and second ridge, could not be 7°.29 C. When we draw north of the northern sill the potential isotherms for 7°.5 and 6°.0 C. according to the trend of that for 9°.0 C., it appears that the depth of the passage here cannot be less than 700 metres, otherwise the bottom temperature would be higher than 7°.29 C. at station 352.

The deepest passage probably lies to the west of the ship's track and station 351 and that may be the reason why the salinity near the bottom at station 352 is a little higher than that belonging to a potential temperature of 7°.29 C. at station 351, just outside the ridge. At all events a combination of potential temperature of 7°.29 C. and salinity of 34.60 °/₀₀ occurs in the Pacific Ocean at station 350 at a depth between 500 to 600 metres.

The second sill, south of station 352, of which the greatest depth, according to the soundings, has been estimated at 940 metres (Fig. 13), prevents a further transport of bottom water at a temperature of 7°.29 C. This saddle-depth cannot be far from the reality, according to the trend of the potential isotherm for 7°.5 C. In any case the depth cannot be much *greater* than 940 metres, otherwise a potential temperature lower than 7°.55 C. would have been observed at station 353 near the bottom.

We must however consider the possibility that this second ridge is much *shallower* and that the minimum temperature which reigns in the Halmahera basin, is caused by a bottom transport from the Ceram sea crossing the *southern* sill, of which the saddle-depth has been estimated at 600 to 700 metres, according to the available soundings. Let us therefore examine Fig. 13 once more.

A flow of bottom water across the southern sill at a depth of about 600 metres may indeed cause a minimum potential temperature of 7°.55 C. in the Halmahera sea, but then this temperature would be accompanied by a salinity of 34.65 to 34.67 °/₀₀, according to the observations at the stations 354 and 354a. This is in contradiction with what was observed near the bottom at station 353.

On similar grounds the possibility of a renewal of the bottom water in the Halmahera basin by a direct transport from the Molukken sea along the passage between Obimajor and Halmahera must be rejected. In that case the salinity at the bottom in the basin would be 34.64 °/₀₀ instead of 34.60 °/₀₀, according to the temperature and salinity observations at the stations 80 and 82. (see Plate III).

The deep tongue extending from the Molukken sea eastward as far as 128°50′ E. may be connected with the Halmahera basin to a depth which does not exceed 560 metres, otherwise the bottom salinity in the Halmahera basin would be much higher.

Summarizing we may conclude that the bottom water in the Halmahera basin is renewed by a transport from the Pacific Ocean across the northern sill and that the saddle-depth of this sill amounts to about 700 metres.

j. CERAM SEA.

The Ceram sea is bounded on the south by the islands Boeroe and Ceram and a submarine ridge at a depth of less than 1000 metres, which lies between the Watoebela islands and the south-west point of New-Guinea; on the north and east by the island Obimajor and the shelf of New-Guinea as far as Cape van den Bosch. The western limit is the submarine ridge between Boeroe and Sanana.

Tydeman (Bibl. 21), who was not aware of the existence of the ridge between the Watoebela islands and New-Guinea, mentions as south-eastern boundary the Kai and Aroe islands. As the deep south-eastern part of the Ceram sea, drawn as a separate basin on Tydeman's chart, forms however one single deep basin with that between the Kai and Aroe islands, it seems preferable to draw the limit a little more to the north in the way we have done.

In the western part of the Ceram sea, known as the Pitt passage, a deep basin is situated, which has been called the Boeroe basin after the island lying in the vicinity.

The area of this basin at a depth of 3000 metres is about 16.000 square kilometres. The western part is deepest; according to previous soundings the greatest depth recorded here is 5319 metres, a depth only little more than the "Snellius"-maximum: 5280 metres. In the eastern part a second deep region is limited by the contour of depth of 4500 metres; in this part the "Snellius" observed the greatest depth of 4680 metres. Between the western and eastern part lies a passage at a depth of 3870 metres at 2°35′ S. and 127°33′ E.

In the Pitt passage the configuration of the sea bottom is rather complicated. From here a narrow depression extends eastward, running at first along the axis of the Ceram sea, afterwards nearing the shelf of New-Guinea. The depth gradually decreases and the 2000-metre line terminates at about 131° E. The shallowest point in the passage which connects the Boeroe basin with the Aroe basin lies at about 3°15′ S. and 131°50′ E., according to the present chart, at 1600 metres.

From here the depth increases towards the south-east, so that to the west of New-Guinea the contour of 2000 metres appears once more on the chart. Between Cape van den Bosch and the ridge which bounds the Ceram sea on the south side, the passage is very narrow. From this point the depth contours diverge and form the wide Aroe basin.

The connection with the Halmahera sea has been treated above (see p. 31 and Fig. 13).

The principal passage, which leads from the Molukken sea to the Ceram sea, is Lifamatola strait between the islands Lifamatola and Obimajor. Measured between these islands it has a width of about 90 kilometres. (detail chart 11).

From Lifamatola a ridge extends to the east, on which depths of less than 1500 metres have been recorded. A similar ridge has been found extending from the south-west coast of Obimajor to the west. These ridges are ranged in echelons so that between them a deeper passage remains, running in a direction west-north-west—east-south-east.

On the sill of this passage the greatest depth has been recorded at 1°50′ S. and 126°57′ E. of 1880 metres, according to detail chart 11. Weber (Bibl. 7, p. 5 and 84) mentions a depth of 1600 metres and Tydeman (Bibl. 21) assumes, in accordance with three soundings in the passage and some temperature observations on both sides of the sill, a greatest depth of 1650 metres.

This passage is considerably deeper than that across the Halmahera sea and consequently the coldest water, originating from the Pacific Ocean, here enters the Ceram sea. On the depth of the sill in this entrance the properties of the abyssal water depend, not only in the Ceram sea but also in the southern and western part of the whole Archipelago.

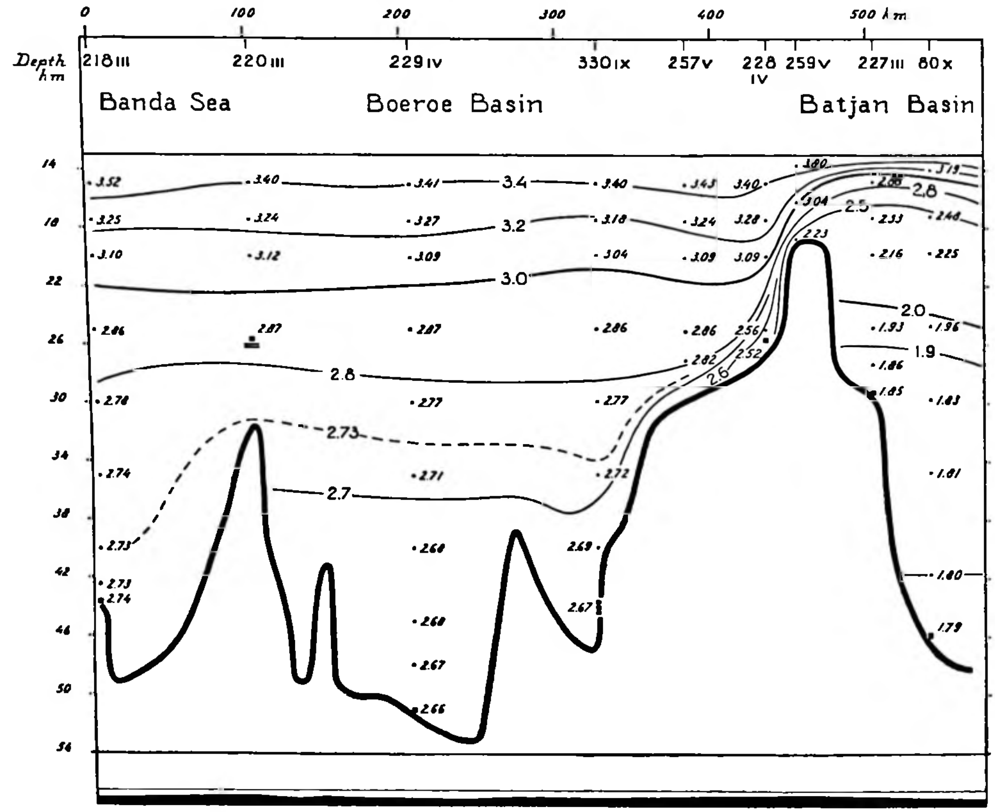

Fig. 14. Section from Molukken sea (Batjan basin) to Banda sea along Ceram sea (Boeroe basin). Potential temperature.

In Fig. 14 (see Plate III) we have given the potential temperature distribution in a vertical section from the Molukken sea (Batjan basin) to the Banda sea along the Ceram sea (Boeroe basin). *On account of the great number of soundings in Lifamatola strait the sill-depth of 1880 metres may be regarded as sufficiently accurate,* so that we are able to determine in this special case the difference between the greatest depth of the sill and the depth in the Molukken sea in which the potential temperature agrees with the minimum potential temperature in the Boeroe basin.

This minimum is 2°.66 C.; a value which occurs at the stations 227 and 80 in the Molukken sea at about 1600 metres.

The saddle-depth will be generally greater than the depth outside the sill, in which the properties of the sea water correspond to those of the abyssal layers inside. But here the difference is rather large i.e. 280 metres. When examining detail chart 11 more closely we observe that the width

of the passage at a depth of 1880 metres is very small, not more than a twentieth part of the width of the strait, whilst on both sides the depth rapidly decreases to 1500 metres and less.

Under the influence of the irregular bottom configuration and probably also of tidal variations in the direction of the sill-current, a powerful mixing will occur in the bottom layer when running through the strait and entering the Ceram sea. Consequently the minimum potential temperature in the Boeroe basin will be much higher than that of the layer in the Molukken sea at a depth equal to that of the sill. It is therefore not sufficient to consider only the minimum potential temperature; we must take into account the distance from the entrance and the increase of temperature along this distance due to mixing and the exchange of heat with the earth's crust.

It is evident that this increase is far greater when the bottom layer passes a strait like that between Lifamatola and Obimajor, than when it flows along a smooth bottom, as for example in the passage between the Timor trough and Aroe basin.

When dealing with the flow of the bottom water and the general circulation between sea floor and surface, there will be opportunity for discussing this subject more thoroughly.

k. BANDA SEA.

The Banda sea is bounded on the north by the Banggai and Soela groups, Boeroe and Ceram. A row of non-volcanic islands, ranging from Ceram along Kai and Tanimbar to Babar island, encircles the Banda sea on the east, whilst on the south side lie the islands between Romang and Flores. On the west this principal inland sea is limited by a ridge, broken by various passages, which runs from the north-east point of Flores along Angelika shoal, Kalaotoa, Kakabia and Batoeata to the island Boetoeng; farther northward by the east coast of this island and of Celebes.

When considering the region, outlined by the contour of 4000 metres, the Banda sea is seen to be divided into three large basins: a *southern* and a *northern* basin and the *Weber deep.*

South of the islands Boeroe and Ceram the present depth chart and detail chart 12 show a less important depression, the *Ambalaoe basin* of which the area at 4000 metres is over 7000 square kilometres. (see also Plate VI).

Between the Toekangbesi islands and the island of Ceram a wide elevation of the sea floor, with sharp contrasts in rises and depressions in the eastern part, separates the northern from the southern basin. This elevation is intersected by a narrow passage, running north-west—south-east, in which the depth is over 4000 metres.

A ridge, the Banda arc, on which lie a row of volcanic islands, ranging from the Banda group to the island Romang, separates the southern basin from the Weber deep. The deepest connection between the two basins of over 4000 metres depth appears to be south-east of the Banda-plateau.

The northern basin. The floor of the northern basin presents a rather flat plain; areas, exceeding 5000 metres in depth, lie scattered in this region. The area at a depth of 4000 metres is over 80.000 square kilometres. The greatest depths (5750 and 5800 metres) have been recorded south of Mangole and north-east of the island Wowoni. In a trough-shaped depression north-east of the Toekangbesi islands the greatest depth is 5450 metres. A narrow ridge at less than 4000 metres extends from the island Wowoni east-north-east.

Fig. 15 shows a section G—H (see Plate III), representing the true-scale bottom contour to the south of the Soela islands. After a slight increase of the depth on the shelf, the sea floor slopes steeply at an angle of 22°. This angle gradually decreases towards point G with the exception of two interruptions at a distance of 15 and 25 kilometres from point H.

From section M—N appears, that the bottom-line to the north-east of the island Manoei (see Plate III) slopes at an angle of about 10° to a depth of 2500 metres. From here the depth gradually increases except for a slight rise between station 214 and point N.

Section E—F represents the true-scale bottom contour off the south-west coast of the island Boeroe (see Plate III). The floor near the coast is very steep, sloping at first at an angle of 26°, afterwards at about 16°. At a distance of about 20 kilometres from the coast the sea floor becomes fairly level at over 5000 metres with an interruption of a slight rise at a distance of approximately 14 kilometres from point E.

The separating rise of the sea floor. In contrast with the remaining part of the Banda sea, the bottom configuration of the elevation between Boetoeng and Ceram is very irregular.

On the western part lie the Toekangbesi islands (detail chart 9). A great number of soundings have been carried out in this region with a view to the irregular relief of the sea floor and the fact that this region, with alternating zones of subsidence and elevation, is considered from a geological standpoint, as an important part of the earth's crust (see Vol. V, Part 1).

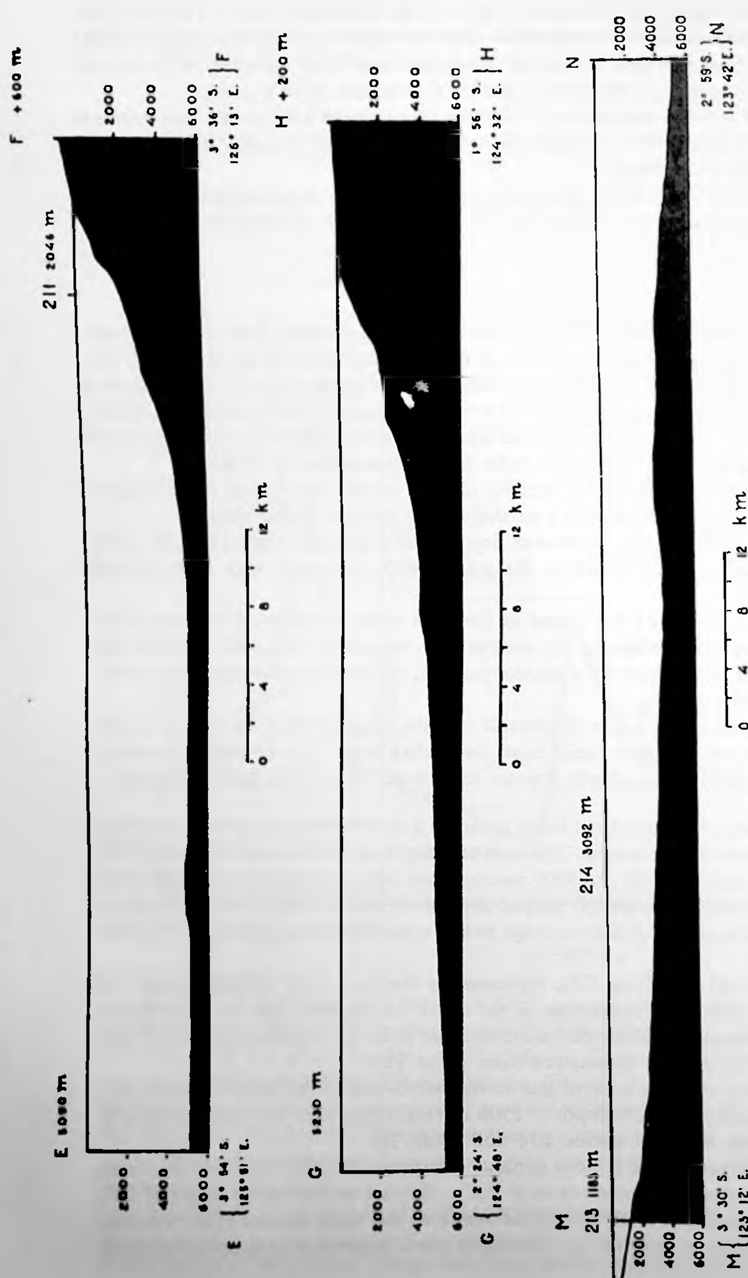

Fig. 15. True-scale bottom contours in the north-western part of the Banda sea.

The slope of the north-eastern and south-western part of the Toekangbesi-plateau is rather steep. Within a short distance of the island Roendoema a depth of over 5400 metres has been recorded. On the south-west side lies the *Boetoeng trough* with an area of 1200 square kilometres at a depth of 4000 metres and a greatest depth of 4180 metres. The axis of this trough, separating the island Batoeata from the Toekangbesi islands, lies in a direction north-west—south-east, in contrast to what has been supposed hitherto. (Tydeman, Bibl. 21). Between the Toekangbesi islands and Boetoeng appears a passage at a depth of 1600 to 1900 metres.

The eastern part of the rise separating the northern and southern Banda basin has a complicated bottom configuration. On the north-western edge, south of Boeroe, a pronounced ridge, hitherto unknown, rises from the floor to a depth of about 530 metres below the surface (the *Luymes ridge*). On the south-eastern edge the previous *Siboga ridge*, represented on Tydeman's chart (Bibl. 21), appears to consist of at least two large isolated elongated ridges,

ranged in echelons and separated by a passage at a depth of over 4000 metres.

When crossing the northern ridge, the shallowest sounding recorded was 1460 metres. This part of the Siboga ridges is connected with the islands to the north of it by the 3000-metre line.

On the southern Siboga ridge the Schildpad and Lucipara islands lie, encircled by the 2000-metre line. Moreover a narrow ridge rises near the eastern extension to a depth of about 1530 metres beneath the surface. A similar elevation appears north of the Lucipara islands with a lowest depth of 1800 metres.

Between the Luymes and Siboga ridges and the islands Boeroe and Ambon lies the *Ambalaoe basin* of which the western part is deepest. The greatest depth, recorded here by the "Snellius", is 5330 and 4940 metres in the eastern part. A very narrow connection at a depth of little more than 4000 metres probably connects both parts.

The southern basin. The southern Banda basin is much like the northern one, in having fairly uniform depths, with some areas exceeding 5000 metres. At 4000 metres the area is about 120.000 square kilometres. The greatest depth recorded, of 5400 metres, has been observed west of Damar islands at about 7°00′ S. and 127°50′ E.

In the centre of this basin the isolated Goenoeng Api (Firemountain) rises from the sea floor amidst depths of over 4000 metres. In the western part the island Komba has a similar position surrounded by depths of about 3500 metres.

In Fig. 16 section I—J (see Plate III) represents the true-scale bottom contour on the north and south side of the island Goenoeng Api. Plate III shows that the echo-soundings, used for constructing this bottom contour, do not lie on a straight course.

To the north of the island the angle of the shore-slope to a depth of 800 metres is about 35°. On the opposite side the bottom gradient is less but the angle of sloping still amounts to 24°, to a depth of about 3000 metres. On the north side the mean gradient to a similar depth is only 10°, followed by an abrupt dip of 27°. On both sides the floor is fairly level in a depth of about 4500 metres.

It is curious to note how only the uppermost part of this massive volcano, which rises from a depth of 4000 metres, is to be seen above the surface of the sea.

Between the island Goenoeng Api and the Toekangbesi group the depths are supposed to be fairly uniform. West of this region however the sea floor appears to be irregular, according to a large number of acoustic soundings carried out by Netherlands submarines in order to fix the position of a reported danger to shipping. Depths less than 2285 metres have not been observed here however.

Fig. 16. True-scale bottom contour on the north and south side of the island Goenoeng Api.

The Banda arc. The northern part of this volcanic ridge (the Banda-plateau) is separated from the southern part and from the Siboga ridges by depths of over 4000 metres. This plateau outlined by the 1000-metre line extends farther to the north than appears from previous depth charts. A tongue at 2000 metres, bending to the west, is connected with the islands south of Ceram (the Oeliassers) by a submarine ridge of which the saddle-depth does not exceed 3160 metres. In the passages between the volcanic islands Manoek, Seroea, Nila and Teoen the depth will be, at all events, less than 4000 metres.

The Weber deep. The Weber deep is the deepest basin within the Archipelago. The

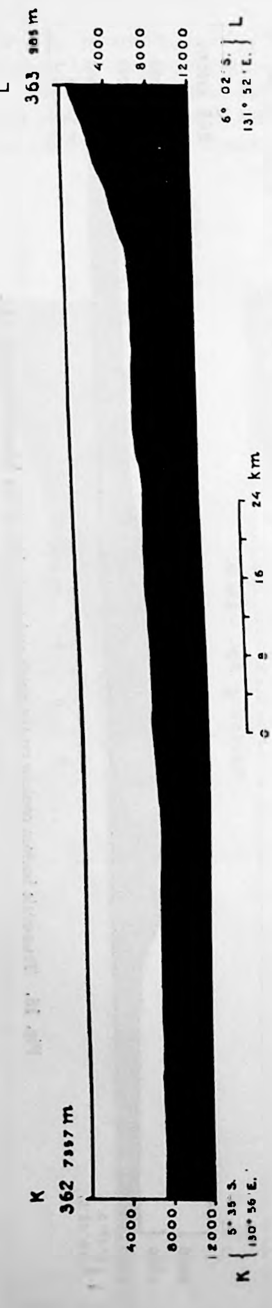

Fig. 17. True-scale bottom contour on the east side of the Weber deep.

greatest depth which has been recorded, is 7440 metres. The area at a depth of 4000 metres is over 50.000 square kilometres.

The region within the depth contour of 7000 metres is fairly uniform in depth. Outside this contour line the depth gradually decreases. The steepest part of the slope lies on the east side, outside the depth contour of 6000 metres.

In Fig. 17 section K—L (see Plate III) represents the true-scale bottom contour in the eastern part of this basin. From station 363 the bottom-line slopes at an angle of 22° to a depth of about 6000 metres; from here the depth gradually and slightly increases till an approximately constant depth of over 7000 metres has been attained.

The Weber deep extends to the west at a depth of 4000 metres as far as the island Damar; towards the north this basin terminates in a narrow tongue between Ceram and the Banda-plateau.

Of the passages leading *directly* from the Molukken sea to the Banda sea, Peleng strait, between the Banggai islands and Celebes, is the deepest. The depth is however only 600 to 900 metres.

Of the passages leading from the Ceram sea to the Banda sea we will first consider the one between Boeroe and the Soela islands.

Tydeman (Bibl. 21) surmises, that the abyssal layers of the Ceram sea are in direct connection with those of the Banda sea at a depth of over 4000 metres. Krümmel's chart (Bibl. 1) shows a shallower connection between Boeroe and Sanana. According to Weber (Bibl. 7, p. 83) Krümmel estimates the depth in this passage at 3660 metres.

As this passage has been regarded as the most important, a great number of soundings were taken here by the "Snellius." The results (detail chart 10) show a ridge, limited by the contour of 3000 metres, extending from Sanana south- and south-westward. Between this ridge and the 3000-metre line surrounding the island Boeroe lies a passage running in a direction south-west—north-east. In the centre of this passage a depth of 2980 metres has been recorded at 2°51′ S. and 126°03′ E. This may point to the occurrence of a sill with a saddle-depth of about 2980 metres. A second and slightly deeper interruption of the sill may exist at 2°45′ S. and 125°58′ E., where soundings are lacking.

Manipa strait, between Boeroe and Ceram, is a less important connection with the Banda sea (detail chart 12). We passed this strait many times and consequently a great number of echo-soundings are available. These were necessary on account of the great complexity of the bottom configuration, which appears from the present large depth charts and detail chart 12.

The entrance on the north side is partly closed by a ridge, running parallel to the islands Boano, Kelang and Manipa, on which a lowest depth of 370 metres has been recorded. Between this ridge and the above mentioned islands a tongue-shaped depression extends from the Boeroe basin as far as Manipa.

North-west of this island a sill appears which separates the Boeroe basin from Manipa strait to a depth of 1150 metres at 3°11′ S. and 127°28′ E.

On the west side of the elongated ridge the passage is probably less deep. According to Tydeman (Bibl. 21) the greatest depth in this entrance is little more than 1000 metres.

Manipa basin. The deep central part of Manipa strait has been named Manipa basin; its area

at 3000 metres is about 2800 square kilometres. The general feature of the floor in this basin appears better if the contour of 3500 metres is drawn as on detail chart 12.

A submarine ridge, outlined by this contour and running west-north-west—east-south-east, divides the basin into two parts, and connects a central elevation, abruptly rising to 900 metres beneath the sea surface, with the islands Boeroe and Ambon.

Both parts of the basin show scattered regions at over 4000 metres; the northern part is slightly deeper; the maximum depth is 4360 metres.

On the south side the basin is separated from the Banda sea by a submarine ridge (the *Ambalaoe ridge*) which connects the island Ambon with Ambalaoe and Boeroe at a depth of probably less than 3000 metres. South and south-west of Ambon, detail chart 12 shows shallower parts, which rise to 800 and 1680 metres below the surface.

The soundings between the most westerly of these two elevations and the island of Ambalaoe suggest a deepest passage across the ridge at about 2830 metres. As the soundings are scarce here, a comparison of the properties of the water in- and outside the sill may throw useful light upon this subject.

Fig. 18 shows the distribution of the potential temperature in a vertical section between the Manipa basin and the Banda sea, crossing the Ambalaoe ridge at about 127°35′ E. (see Plate III).

Near the floor at station 255 a potential temperature of 2°.82 C. was observed. This station lies a little distance to the south of the submarine ridge connecting the central rise with Boeroe.

The potential isotherm for 2°.82 C. has been drawn in accordance with that for 2°.85 C. From the trend of the isotherm it follows, that the passage in the Ambalaoe ridge must be deeper than 3000 metres, so this depth contour has been drawn open at about 127°35′ E.

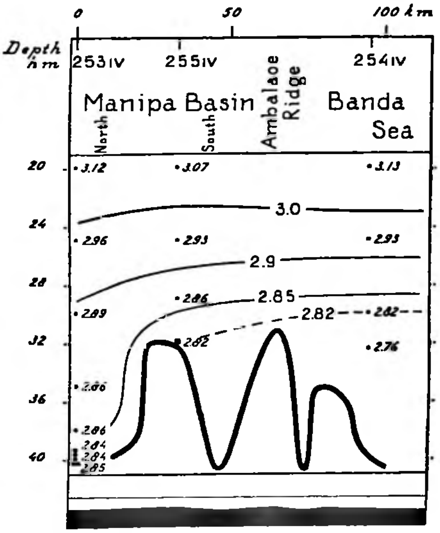

Fig. 18. Section from Banda sea to Manipa basin. Potential temperature.

The ridge connecting the central rise with Boeroe appears to have a passage at 3190 metres according to the soundings, a depth which agrees with the representation shown in figure 18. On the east side of the central rise the depth is over 3400 metres according to the soundings; *here* the bottom-current at a potential temperature of 2°.82 C. probably crosses the ridge in a slightly lower depth, causing a minimum potential temperature at station 253 of 2°.84 C. As the layers are almost homohaline, the salinity does not give any assistance.

Summarizing we may conclude that the bottom water of the Manipa basin is renewed by water from the Banda sea crossing the Ambalaoe ridge in a depth of about 3100 metres and flowing to the northern part, after passing a second ridge at a depth slightly lower than 3400 metres.

Besides the Manipa strait and the passage between Boeroe and Sanana there exist other less important connections between the Ceram and the Banda sea.

The islands south-east of Ceram are connected to it by the 500-metre line as far as the Watoebela islands. Between this group and Manawoka the "Snellius" observed a sill at 430 metres. Tydeman (Bibl. 21) surmises, that the greatest depth on the Ceram arc, between Ceram and the Kai islands, will probably be less than 500 metres. Though according to the present map the passage south of Watoebela islands will be slightly deeper, it appears that these passages are of no importance, for the exchange of bottom water between Ceram and the Banda sea.

Of the various entrances to the Banda sea the passage between Boeroe and Sanana appears to be the most important. The fair sheet shows a sill here at about 2980 metres, but the echo-soundings leave the possibility open of a deeper passage.

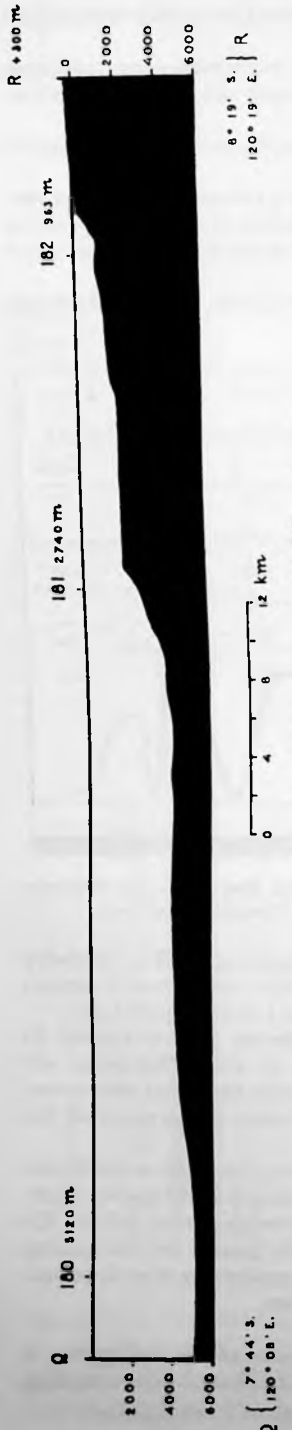

Fig. 19. True-scale bottom contour in the southern part of the Flores sea.

To test the verity of the supposition of a sill in this depth the potential temperature distribution in a longitudinal section should be consulted.

In Fig. 14 (see p. 34) the temperature profile Molukken sea (Batjan basin) — Ceram sea (Boeroe basin) has been continued as far as station 218 in the northern basin of the Banda sea (see Plate III). At this station a minimum potential temperature of 2°.73 C. has been observed near the floor. The depth in the Ceram sea in which this potential temperature has been observed is about 3300 metres.

Though the potential isotherm for 2°.8 C. ascends from station 229 towards the passage and a similar slope may be surmised for the isotherm for 2°.73 C., this slope is not sufficient to allow the water volumes at a potential temperature of 2°.73 C., occurring at station 229 in 3300 metres, to cross a sill in 2980 metres. *According to the trend of the isotherms in Fig.* 14 *the saddle-depth will not be shallower than 3130 metres.* On this assumption the contour of depth of 3000 metres has been interrupted on detail chart 10 between the two ridges, extending from Sanana and Boeroe. Krümmel's estimation of 3660 metres would cause a minimum potential temperature in the northern basin of the Banda sea, lower than that observed at station 218.

It should be noted that the above inferences are based on very small differences in temperature. The temperatures observed in the Boeroe basin at different times in 2500 to 3500 metres are however mutually in good agreement and point to stationary conditions.

1. FLORES SEA. ((Detail charts 6 and 8).

The Flores sea is bounded on the west and north by the Paternoster and Postiljon islands, the south coast of Celebes and the row of islands ranging from Tana Djampea to Kalaotoa. On the east is a plateau on which lie the island Soekoen and the Angelika shoal; on the south this sea is bounded by Flores and Soembawa as far as the Saleh bay.

The south side of the Flores sea shows very steep slopes in the bottom-line. The section Q—R in Fig. 19 represents the true-scale bottom contour off the north coast of Flores (see Plate III). At a distance of 7 kilometres from point R the sea floor slopes abruptly at an angle of 33°. A similar steep portion has been observed near station 181.

We must, however, remark that owing to the drift of the ship during the observations at the stations, the sequence of soundings is repeatedly interrupted, so that in general each sounding-track between two stations must be considered separately.

Moreover in this particular case the construction of the bottom-line offered some difficulty owing to the fact that the ship, after finishing the station 181, ran north for 20 minutes and then came back to her previous course in a southerly direction.

The central part of the Flores sea, outlined by the contour

of depth of 3000 metres has been called the Flores basin. In this depth the area is the same as that of the Sawoe basin, i.e. over 30.000 square kilometres.

The deepest part of this basin, enclosed by the contour of 5000 metres, is trough-shaped and runs parallel to the island of Flores. According to a previous wire sounding, the greatest depth has been recorded at 5140 metres, north of the island Paloë, and according to the echo-sounding at 5130 metres in a second smaller depression in the eastern part of the basin.

A single wire sounding of 4062 metres at 7°15′ S. and 119°15′ E. is probably excessive. It has been maintained on the chart in view of the sudden increase of depth to 3510 metres on a track at a short distance to the south of this single sounding.

Of the various passages, leading to the Flores basin, we mention the following:

Sape strait, east of the island Soembawa, connects the Flores sea with the Indian Ocean; the depth is about 220 metres in the axis of the strait.

The western part of the Flores sea (detail chart 6) terminates in a tongue-shaped extension, which widens towards the west into the Bali sea.

On the north side the floor slopes gradually between the Postiljon islands and Salajar towards the wide plateau, lying south-west of Celebes, and separating the Flores sea from Makassar strait. In the passage between Laars banken and the south-west point of Celebes, connecting the two basins, lies a sill at about 650 metres.

Detail chart 8 shows the principal entrance to the Flores sea, drawn on a larger scale. A ridge outlined by the contour of depth of 2500 metres extends from the north-east point of Flores towards the north-west. A similar contour line connects Angelika shoal with the plateau of the Kalaotoa group.

The soundings here allow two representations of the bottom configuration:

1°. These two ridges are in echelons, leaving a passage deeper than 2500 metres.

2°. The two ridges are connected by the 2500-metre line.

Ad. 1°. The first representation is that from the fair sheet. In this case a U-shaped passage at more than 2500 metres leads from the Banda sea to a small but deep basin, south of Angelika shoal. In the eastern part of this passage lies an *outer* sill with a saddle-depth of 2560 metres at 7°48′ S. and 122°34′ E.

The soundings between Angelika and the island Soekoen are scarce, so that the depth of the sill between the above mentioned small basin and the Flores sea is uncertain, but must be at least 2570 metres. This we will call the *inner* sill.

According to this interpretation the Flores sea would be in direct connection with the Banda sea to a depth of 2560 metres.

Weber (Bibl. 7, p. 36) and Tydeman (Bibl. 21, p. 93) come to the same conclusion, though they had at their disposal only a small number of wire soundings, carried out during the Siboga-expedition.

Ad. 2°. An outer sill at 7°48′ S. and 122°34′ E. in 2560 metres can only be assumed if the ridges are not connected. To verify this connection we may consult the distribution of the properties of the sea water inside and outside the Flores sea.

Fig. 20 shows a potential temperature profile along the stations 194, 318, 317 and 197 (see Plate III). At station 317, situated in the small basin to the south of Angelika shoal, a minimum potential temperature of 2°.97 C. was observed at 2800 metres.

When in Fig. 20 we draw the potential isotherm for 2°.97 C. in accordance with that for 3°.0 C., it becomes evident, that the depth of the *outer* sill cannot exceed 2450 metres, otherwise the temperature in the small basin would be lower than 2°.97 C. Consequently this small basin must be separated from the Banda sea by a continuous submarine ridge which, limited by the depth contour of 2500 metres, connects Flores with Angelika shoal and Kalaotoa. *The deepest passage in this ridge probably lies east of Angelika shoal at 7°43′ N. and 122°25′ E. at about 2450 metres.*

There remains the saddle-depth of the *inner* sill between the small basin and the Flores sea. This depth has been estimated at at least 2570 metres. The trend of the potential isotherm for 2°.97 C. in Fig. 20 however, suggests that this inner sill cannot be shallower than 2750

or even 2800 metres (the latter is used in Fig. 20), otherwise it would be difficult to explain the minimum potential temperature of 2°.96 C. in the Flores sea. This could only be done by assuming, instead of an outer and inner sill, only one single passage crossing the ridge *to the north* of Angelika shoal at a depth of about 2450 metres. When considering the general trend of the depth contours on detail chart 8 and the available soundings, this surmise does not seem very probable.

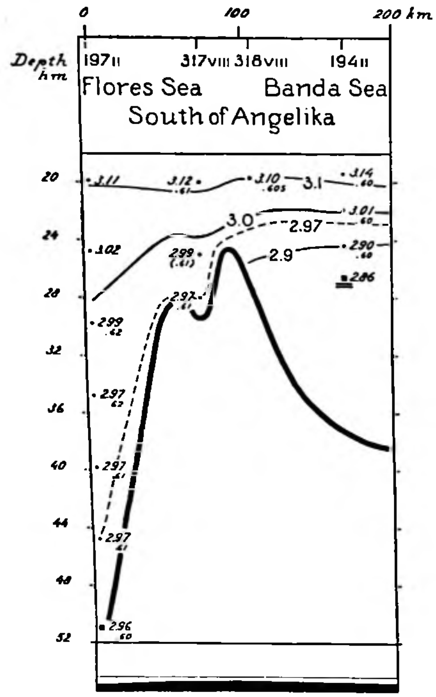

Fig. 20. Passage to the south of Angelika shoal between Banda and Flores sea. Vertical section potential temperature.

Summarizing we may conclude that the saddle-depth in the passage between Banda and Flores basin amounts to about 2450 metres.

m. BALI SEA.

From the narrow passage between the Paternoster islands and Soembawa the 1000-metre line widens westward into the Bali sea, in the centre of which the greatest depth recorded is 1590 metres.

The Bali sea is connected with the Indian Ocean by Bali strait, Lombok strait and Alas strait. The first and last mentioned passages are closed by the 200-metre line and, according to the present map, a sill in Lombok strait lies east and west of Noesa Besar at 210 to 220 metres.

A narrow passage, limited by the 500-metre line and running parallel and close to the shelf of the Java sea, connects the Bali sea with Makassar strait. This passage will, however, not be deeper than 600 metres, so that the coldest layers in the Bali sea must originate from the Flores sea, crossing a sill to the south-east of Maria Reigersbergen bank at a depth of about 1600 metres. From this sill passing westwards, the depth increases to 1810 metres in the narrowest part of the entrance and from there decreases gradually.

n. GULF OF BONE AND THE AREA TO THE SOUTH-EAST.

This region is separated from the Banda sea by a wide ridge, extending between the islands Boetoeng and Kalaotoa. On this ridge lie the islands of Batoeata and Kakabia.

After the first visit to this region the soundings showed a passage between these islands at a depth not exceeding 2180 metres. As the properties of the bottom layers inside the ridge compared with those outside pointed to the existence of a deeper passage, the region between Kakabia and Kalaotoa, which according to Tydeman's chart was less than 2000 metres deep, was investigated later on. The results eventually showed a narrow passage to the *south* of Kakabia at a depth of over 3200 metres. From here the depth gradually decreases towards the west and afterwards north-north-west in the Gulf of Bone.

This region must therefore be regarded as being an extension of the western Banda sea and in direct horizontal connection with it, down to the greatest depth. The floor is rather flat, sloping gently towards the western and eastern borders.

o. SALAJAR TROUGH.

The area to the south of the Gulf of Bone is bounded on the west by a ridge, which

connects the Tijger islands with Celebes. Between this ridge and the island Salajar a narrow trough — the Salajar trough — is situated, of which the area at 2000 metres is about 4000 square kilometres. The greatest depth recorded here is 3370 metres.

The eastern ridge shows between the Tijger islands and Celebes a deeper part across which the abyssal water in the trough may be renewed at a depth of about 1270 metres, according to the available soundings.

The depth in the strait between Salajar and Celebes is less than 500 metres and in the entrance to the south of Salajar about 900 metres. Moreover there may be a second connection with the Flores sea, which is much deeper and runs between Tana Djampea and the Tijger islands and farther eastward north of Kalao. Here soundings are lacking.

As we are not sure of the depth of the deepest passage leading to the Salajar trough, a profile has been given in Fig. 21, which shows the distribution of potential temperature and some salinity determinations in a vertical section from station 192 in the Gulf of Bone, across the western boundary, through the Salajar trough and the narrow passage to the south of Salajar as far as station 178 in the Flores sea. (see Plate III).

The minimum potential temperature in the Salajar trough is 3°.67 C. In Fig. 21 the potential isotherm for 3°.7 C., east of the sill between the two basins, has been drawn in accordance with those for 3°.8, 3°.9 and 4°.0 C. From the trend of the isotherms appears that, if the depth of the sill is indeed only 1270 metres, the lowest potential temperature in the trough would be about 4°.0 C. To cause a minimum of 3°.67 C., the bottom-current must cross the sill at about 1350 metres. A closer examination of the fair sheet reveals, that a similar passage may occur at 5°53′ S. and 120°50′ E.

That the deep water from the trough originates from the Gulf of Bone does not appear only from the temperature but also from the salinity distribution. In the Gulf we observed at station 192 in the sill-depth 34.60 °/₀₀ which agrees with the salinity at station 187 near the floor.

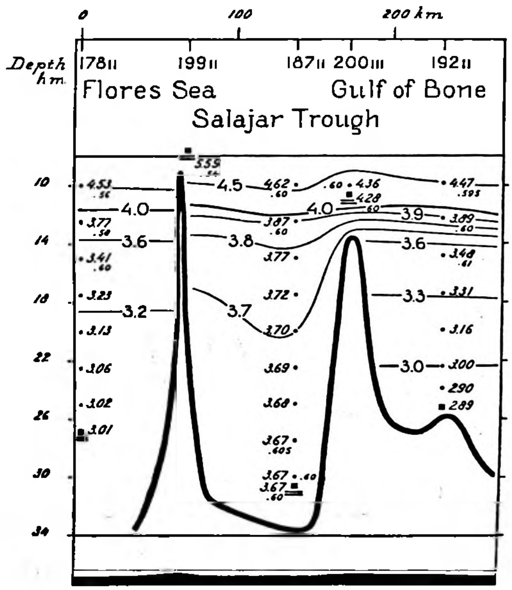

Fig. 21. Section from Gulf of Bone to Flores sea along Salajar trough. Potential temperature and salinity.

In the second connection with the Flores sea between Tana Djampea and the Tijger islands, the depth of the sill must be less than 1500 metres, according to the temperature distribution. The 1500-metre line has been drawn in accordance with this on the depth chart.

As long as nothing definite is known about the depth in the latter passage *we assume for the present, that the abyssal layers in the Salajar trough are renewed by a transport of water from the east, crossing the sill in a depth of about 1350 metres.*

p. WETAR STRAIT.

The Wetar strait, situated between the islands Wetar and Timor, is bounded on the west by a submarine sill between the islands Kambing and Timor; on the east by an irregular plateau, separating the strait from the Weber deep.

The central part of the strait, the Wetar basin, has an area at 3000 metres of about 6000 square kilometres. The present map shows that the bottom of the basin lies in fairly uniform depths. In

this connection there is some likeness with the adjacent Weber deep. The greatest depth is however considerably less, namely 3460 metres.

In contrast with the Weber deep and Wetar strait the configuration of the sea floor in the region which separates the two basins, is rather complicated. On a platform, limited by the contour of depth of 3000 metres, lie on the north-western and south-western edge the islands of Romang and Kisar, whilst a central ridge rises to 1480 metres beneath the surface.

To the north and west of this central ridge a deep passage connects the Weber deep and the southern Banda basin with the Wetar basin. This passage is of less importance for the renewal of the abyssal layers in the Wetar basin as the depth of the sill to the south of Romang cannot exceed 2200 metres.

The southern passage has a sill to the north of the island Moa, in which a saddle-depth of 2700 metres has been recorded. Farther to the west this passage runs through a small trough at a depth of more than 3000 metres and afterwards on both sides of the island Kisar to the Wetar basin. According to the available soundings the depth on the sill east of Kisar exceeds 2700 metres.

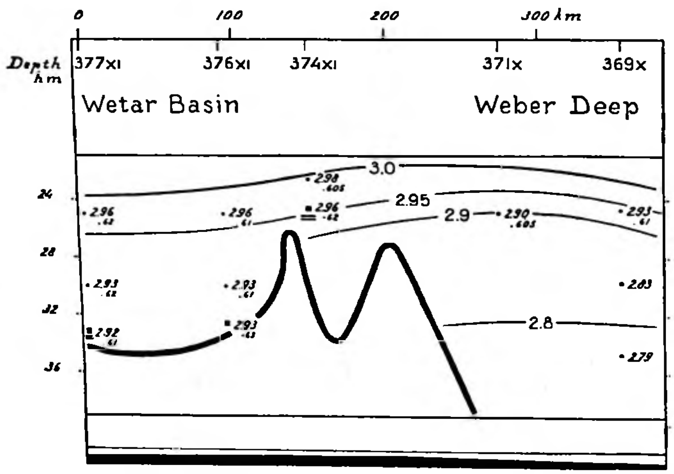

Fig. 22. Section between Wetar basin and Weber deep. Potential temperature and salinity.

Two more passages must be mentioned, establishing a direct connection with the southern Banda sea. These lie to the north of the island Kambing and between the islands Romang and Wetar. In the former the saddle-depth will be about 1040 metres; between Romang and Wetar no soundings are available, so that we must consider the properties of the sea water in- and outside the basin to ascertain, whether this passage plays an important part in the circulation of the abyssal layers in the Wetar basin below a depth of 2700 metres.

The first thing to be considered is whether the depth in the passage to the east of Kisar — which is the deepest according to the soundings — really exceeds 2700 metres.

Fig. 22 shows the potential temperature distribution and some salinity determinations in a vertical section from station 369 in the Weber deep, across the outer sill, through the small trough to the north of Leti and the passage to the south of Kisar as far as station 377 in the Wetar basin. (see Plate III).

The lowest potential temperature in this basin is 2.°92 C. When to the east of the sill near station 374, we draw the potential isotherm for 2°.9 C. in accordance with that for 2°.95 C., the figure shows, that the lowest potential temperature in the Wetar basin would be less than 2°.92 C., if the depth of the *inner* sill exceeded 2700 metres. This would not be so if the *outer* sill allowed an inflow of bottom water at a temperature *not lower* than 2°.92 C. But in that case the saddle-depth of the *outer* sill would be about 2500 metres and this is in contradiction to a sufficient number of soundings. Consequently the depth of the *inner* sill has been estimated at about 2600 metres in correspondence with the trend of the potential isotherms in Fig. 22. If the soundings plotted on the fair sheet are carefully examined, the possibility of a similar sill to the east of the island Kisar becomes apparent.

In the second place we have to estimate the depth between Romang and Wetar, where no soundings have been taken.

Fig. 23 shows the vertical potential temperature distribution between the southern Banda sea and the Wetar basin with some salinity determinations (see Plate III). According to the original drawing the depth of this passage would be more than 3500 metres. If this were right, the Wetar basin would be in open connection with the southern Banda sea and the minimum potential temperature in the basin would be about 2°.8 C.

When in Fig. 23 we draw the potential isotherm for 2°.95 C. parallel to those for 3°.0 and 3°.1 C., the trend of the isotherms shows that this passage cannot be deeper than 2450 metres. The contour of depth of 2500 metres has been drawn in accordance with this on the depth chart.

Judging from the difference in temperature at 2500 metres on both sides of the sill we may expect a slightly smaller depth. This has been indicated in Fig. 23 by interrupting the potential isotherm for 2°.95 C. and assuming a depth of 2400 metres.

When comparing the salinity values near the floor at station 374 (Fig. 22, p. 44) and those in the Banda sea (Fig. 23) with those of the bottom water in the Wetar basin it appears that these results also confirm what has been stated above.

Summarizing we may conclude, that the bottom water of the Wetar basin is renewed by water from the Weber deep running to the south of the central ridge and crossing a sill to the east of the island Kisar at a depth of approximately 2600 metres.

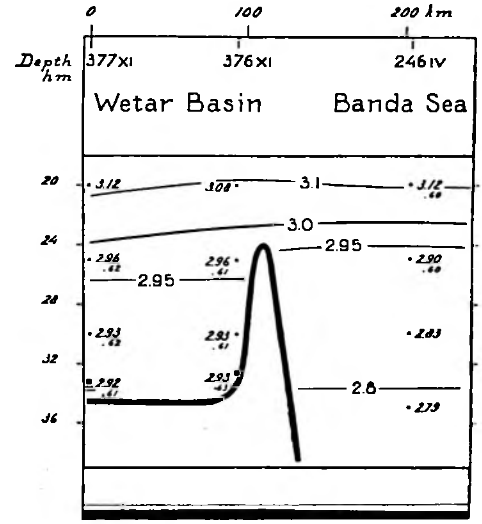

Fig. 23. Section between Wetar basin and Banda sea. Potential temperature and salinity.

q. SAWOE SEA.

The Sawoe sea lies between the two rows of islands: Soemba — Sawoe — Roti — Timor on the south and Flores — Solor — Lomblen — Pantar — Alor on the north.

The central and eastern part is deepest; the region outlined by the contour of depth of 3000 metres has been called the Sawoe basin. Its area at this depth is about 30.000 square kilometres. The configuration of the sea floor appears to be much like that of the Wetar basin; no sharp contrasts in rises and depressions have been recorded. The greatest depth, 3470 metres, occurs to the south of Pantar strait. In the extreme eastern part (Ombai strait) lies an isolated depression of the sea floor, outlined by the depth contour of 3250 metres, in which a greatest depth of 3390 metres has been recorded. (See also detail chart 7).

The Sawoe sea is connected with the Banda sea by various passages. Of these Flores and Boleng straits are closed by the 200-metre line; in Alor strait no deep soundings are available; anyhow we may estimate the depth at less than 1000 metres. According to detail chart 7, the depth in Pantar strait will not be much more than 600 metres.

This detail chart shows a deepest passage at about 1260 metres across the sill between the islands Alor and Kambing, so that this passage establishes the deepest *direct* connection from the Sawoe sea with the Banda sea.

From the Indian Ocean three passages lead to the Sawoe sea, i.e. the Soemba, Sawoe and Dao straits. Tydeman supposes the Soemba strait to be less than 1000 metres deep. According to the "Snellius"-soundings the saddle-depth must be about 900 metres.

Both passages east and west of the island Sawoe have been investigated thoroughly as may appear from the large number of soundings plotted on detail chart 5. In order to give a better idea of the topography of the sea floor in both straits, the contour line of 1200 metres has been added to the ordinary ones for: 3000, 2000, 1500, 1000, 500 and 200 metres.

Two bends of this contour line of 1200 metres extend from the north and south in Dao strait, leaving a sill east-south-east of the island Sawoe at 1140 metres at 10°39′ S. and 122°16′ E.

In the Sawoe strait (detail chart 5) the contour of depth of 1200 metres extends from the Indian Ocean as far as the northern part of the passage, where a sill appears, approximately 1160 metres below the surface at 10°12′ S. and 121°20′ E. Weber (Bibl. 7, p. 84), judging by soundings of the Siboga-expedition, estimates the greatest depth to be 1400 metres and Tydeman (Bibl. 21), who merely mentions the Sawoe strait, overestimates the saddle-depth by about 250 metres.

These passages show much likeness in the topography of the sea floor. Sawoe strait is a little wider between the contour lines of 500 metres and the sill may be slightly deeper, though in the axis of Dao strait the depth may be a little over 1140 metres.

Finally we come to the connection between Wetar basin and Sawoe basin (or Ombai passage as the east part of the Sawoe sea is called).

Between Timor and the island Kambing, Tydeman's chart shows a deep depression in the narrowest part and a sill more to the west at a depth of over 2000 metres. According to the soundings taken on the track of the "Snellius" along the axis of the passage, the lowest depth recorded on the sill is 1815 metres.

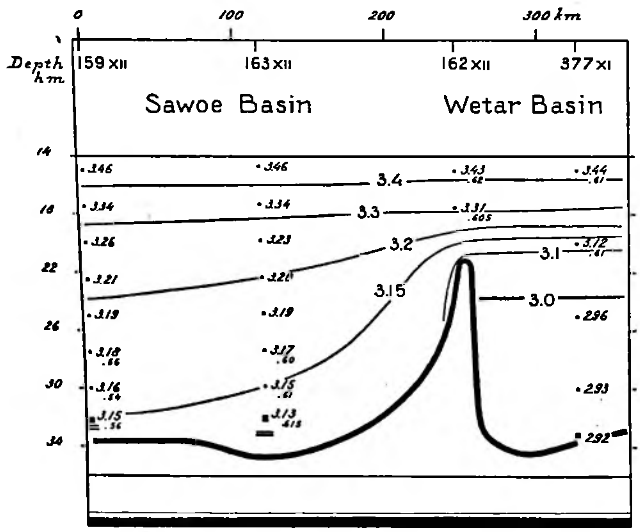

Fig. 24. Section between Sawoe basin and Wetar basin. Potential temperature and salinity.

Summarizing we have, according to the soundings, the deepest connection with the Banda sea at 1260 metres, with the Indian Ocean at 1160 metres, with the Wetar basin at 1815 metres. This last passage is apparently the most important for the renewal of the bottom layers in the Sawoe basin, so it will be advisable to ascertain whether the saddle-depth is actually 1815 metres, by comparing the properties of the sea water outside the entrance with those of the bottom water in the Sawoe sea.

Fig. 24 shows the distribution of potential temperature and some salinity observations in a vertical section between Wetar basin and Sawoe basin. (see Plate III). The lowest potential temperature observed in the Sawoe basin is 3°.13 C. near the bottom at station 163. To our regret temperature and salinity observations at station 162 near the bottom are lacking. When to the east of the sill we draw the potential isotherms for 3°.2, 3°.15 and 3°.1 C. in accordance with that for 3°.3 C., it appears, that a saddle-depth of 1815 metres (according to the soundings) would be accompanied by a much higher potential bottom temperature (about 3°.3 C.) at station 163. From the representation given in figure 24, it appears that the saddle-depth must be about 2100 metres.

When examining the soundings on the fair sheet more closely, a passage at a similar depth appears to be possible, north and south of the single sounding at 1815 metres plotted on detail chart 7. Consequently the depth contour of 2000 metres has been drawn open on this chart and the sounding in 1815 metres has been regarded as taken on an isolated rise of the sea floor. Fig. 24 shows that not only the temperature but also the salinity observations in the 2100-metre layer in the Wetar basin and those in the bottom layer at station 163 in the Sawoe basin are in good, agreement.

The cause of the lower salinity near the bottom at station 159 will be discussed in another chapter, when dealing more extensively with the flow of the bottom water.

That both connections with the Indian Ocean to the west and the east of Sawoe are much shallower than the passage between Sawoe and Wetar basin is clearly shown on detail chart 5 so that, with a vertical temperature distribution in the Ocean *equal to that* in the Wetar basin, an oceanic bottom transport, renewing the bottom layers in the basin, may not be expected.

However the temperature in the Indian Ocean is much *lower* than that in the Wetar basin. In the Ocean we observed at station 382 a potential temperature of 3°.13 C. (the minimum in the Sawoe basin), at a depth of about 1600 metres against 2000 metres in the Wetar basin.

This great difference is however not sufficient to allow a renewal of the bottom layer in the Sawoe basin by a transport from the Indian Ocean. This appears clearly from Fig. 25, representing a vertical section for potential temperature distribution through the Sawoe strait (see Plate III).

What holds good for this passage is also true for the Dao strait and even more for the shallower Soemba strait.

Summarizing we may conclude that the bottom water from the Sawoe sea is renewed by water from the Wetar basin, crossing the sill between the islands Timor and Kambing at a depth of about 2100 metres.

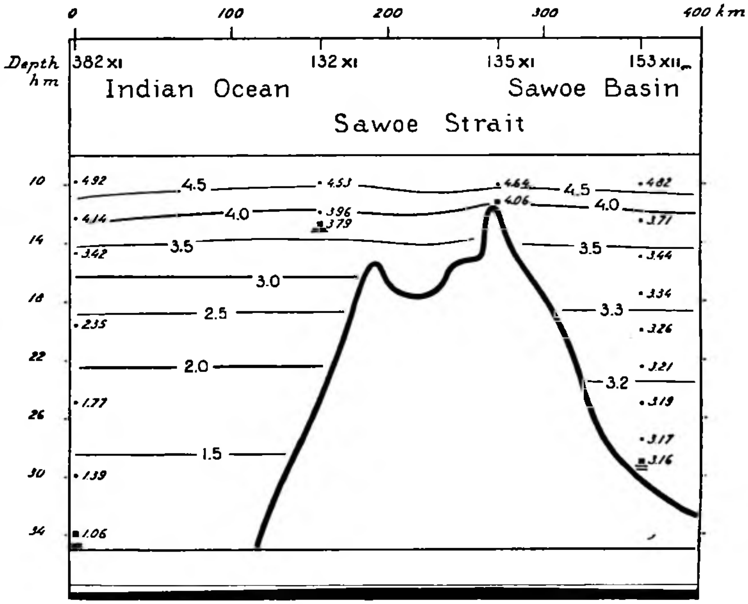

Fig. 25. Sawoe strait. Section between Sawoe basin and Indian Ocean. Potential temperature.

r. THE ADJACENT PART OF THE INDIAN OCEAN.

A great number of soundings have been taken to the south and south-west of the Sawoe sea, in order to get a better view of the connection between the deep trough-shaped depression lying to the south of Java (the Java trough) and that bordering the Sahoel-shelf (the Timor trough). To the west of 117° E. the contours of depth are based on previous soundings. Though this material is less homogeneous than that of the "Snellius", it is sufficient to give a fairly trustworthy representation of the topography of the sea floor.

The present maps show to the south of Java, Bali, Lombok and Soembawa the eastern part of a depression of the sea floor, which runs parallel to the south and south-west coast of Java and Sumatra as far as the Mentawei trough. This eastern part has a depth of over 4000 metres; a single previous sounding at 115°30′ E. shows a depth of 5160 metres.

Outside this depression a parallel ridge appears at a depth of less than 3000 metres, which runs to the west and north-west and bears the row of islands to the south-west of Sumatra. This ridge is separated from the row of islands Soemba, Sawoe, Roti, etc. by a deep passage connecting the northern depression with the Java trough. The "Snellius" crossed this trough three times, sounding depths which exceed 6000 metres. The present map shows the greatest depth at 7140 metres at 113°41′ E.

The narrow 6000-metre area extends eastwards as far as 119°30′ E. Tongue-shaped bends of the successive contour lines terminate with the last bend of the 2000-metre line near the sill of

the Timor trough, to the south of the island Roti. The axis of the Java trough and of the eastern tongue is continued by that of the Timor trough and the depression lying outside the Ceram arc and bordering the Australia—New-Guinea-shelf.

s. TIMOR SEA.

The Timor sea includes the region lying between Timor and the meridian of 130° E. Of this region only the deeper part outside the Australian-shelf has been investigated.

In this region a deep depression extends from the Indian Ocean to 130° E. The central part, outlined by the depth contour of 2000 metres, has been called the Timor trough, the area of which amounts to about 30.000 square kilometres. The deepest part lies between 126° and 128° E.; here the greatest depth has been recorded at 3310 metres.

Following the axis eastwards the depth decreases and a very narrow passage between the 1000-metre lines, lying to the east of the Tanimbar islands, connects the Timor trough with the Aroe basin.

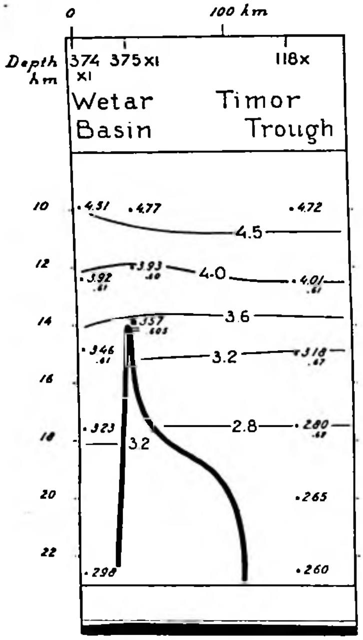

Fig. 26. Section between Wetar basin and Timor trough across the sill to the east of Timor. Potential temperature and salinity.

The row of islands and reefs, extending from Sermata to Leti (east of Timor), lie on a ridge, limited by the 1000-metre line. Between Leti and Timor the connection between the Wetar basin and the Timor trough, however, is deeper. In accordance with previous soundings, Tydeman (Bibl. 21) supposes there to be a sill at a greatest depth of something more than 1200 metres. The greatest depth, according to the latest soundings, is 1620 metres. This sounding has been probably taken on the south side of the sill, so that the saddle-depth will be shallower.

This surmise is confirmed by the potential temperature and salinity distribution given in Fig. 26 in a vertical section between the Timor trough and Wetar basin, across the sill in the passage between Timor and Leti. (see Plate III).

To a depth of about 1400 metres there is only little difference between the potential temperature and the salinity observed to the north of, near, or to the south of the sill; in 1500 metres however the difference is large and a direct connection at a depth of 1620 metres may therefore be regarded as highly improbable. From the trend of the potential isotherms we may conclude, that the saddle-depth will be approximately 1400 metres. The depth contour of 1500 metres has consequently been drawn closed in the passage between these islands.

According to detail chart 4 the curved passage between the islands Babar and Sermata has a sill to the east of Sermata. Here the passage, which originally runs in a direction west — east turns towards south-west. The deepest spot of this sill lies at 8°20′ S. and 129°25′ E. in a depth of 1220 metres. The sounding of 1100 metres probably belongs to the edge of the ridge extending from Sermata eastwards. Tydeman suggests a saddle-depth of less than 1500 metres.

The principal entrance to the Timor trough is from the Indian Ocean. The representation on detail chart 5 shows an outer and an inner sill to the south of the island Roti, between which a small depression, at a depth of a little more than 2000 metres occurs. The outer sill lies at a depth of 1970 metres at 11°17′ S. and 122°51′ E. On the inner sill the greatest depth of 1940 metres has been observed at 11°11′ S. and 123°03′ E. This is about 350 metres more than has been supposed hitherto (Bibl. 21).

The other entrances to the Timor trough are considerably less deep. *Consequently the bottom*

layers of this trough are renewed by water from the Indian Ocean crossing the sill to the south of Roti at about 1940 metres. This is confirmed by the distribution of potential temperature and salinity, as will appear when dealing with the flow of the bottom water. A vertical section has not been given here, as we do not doubt the accuracy of the large number of echo-soundings which at stations 156 and 130 are in good agreement with the wire sounding and the depth derived from the reading of both protected and unprotected thermometers.

t. THE ARAFOERA SEA AND THE AROE BASIN.

The Arafoera sea embraces the region between New-Guinea and Australia, from Torres strait to the Tanimbar islands, the Kai islands and the meridian of 130° E. Of this region only the deep depression bordering the Arafoera sea on the west side has been investigated to the 200-metre line. The greater part of the Arafoera sea is shallow and lies within this contour of depth.

According to Tydeman's chart (Bibl. 21), the narrow depression, extending from the Timor trough, ends on the north side in two separate troughs. The present map shows only one basin: the Aroe basin, which extends from 6°20′ S. to the coast of New-Guinea.

The area at a depth of 3000 metres is about 11.000 square kilometres; the greatest depth has been recorded in the southern part as 3680 metres. Within the 3000-metre line the depths are fairly uniform. To the north-east of the Kai islands the chart shows an elevation, on which the smallest depth of 530 metres has been recorded.

To the south-west a narrow passage, limited by the 1000-metre line, leads to the Timor trough. According to the scanty number of soundings on three crossings the depth in this passage to the east of the Tanimbar islands in the axis of the trough-shaped depression is fairly uniform along a distance of about 300 kilometres. The smallest depth in the axis appears to be 1600 metres on the cross-section to the south-east of Jamdena.

As we have seen above (see p. 33) the shallowest point in the narrow passage between the Boeroe and Aroe basin lies at 3°15′ S. and 131°50′ E. also at 1600 metres, according to the available echo-soundings.

We have further to consider the connections of the Arafoera sea with the Banda sea. This inland sea is bordered on the east by a curved submarine rise, on which lie a row of smaller and larger islands of which the Kai and Tanimbar groups are the most important. This rise, limited by the contour line of 1000 metres, extends from Ceram as far as the Babar islands. (129° E.). The passages which connect the Banda sea with the Ceram sea have been already discussed (see p. 38).

Of the connections between the Banda sea and the Arafoera sea we will consider those:

a. between the Kai islands and Tanimbar islands.

b. between the Tanimbar islands and Babar.

a. According to Tydeman's description, the passage across the Ceram arc to the south of the Kai islands is not deeper than 700 metres. As the "Snellius" did not cross this wide submarine rise, soundings only on the west and east edge are available. From these we may however conclude, that the 1000-metre line is closed here.

b. The bottom configuration on the north side of the passage between the Babar and Tanimbar islands is very complicated. The 1000-metre line shows a great bend to the south between the two groups of islands; in the centre of this bend lies an isolated depression in depth exceeding 3000 metres, followed to the north by an abrupt rise of the floor to 1660 metres beneath the surface.

A sounding in 2040 metres at 7°07′ S. and 130°38′ E. suggests shallower depths towards the west, forming an elongated ridge bordering the Weber deep. This ridge may be regarded as a continuation of the considerably shallower one, extending in a direction south-west—north-east to the north of the island Dawera. (detail chart 4).

The 500-metre line between Babar and the Tanimbar islands has been drawn on detail chart 4 and the large map so, that both ridges extending from Babar eastwards and from Selaroe westwards are connected, leaving a saddle-depth of about 430 metres. Tydeman (Bibl. 21) estimates the greatest depth at less than 1000 metres.

The available data allow however other representations of the bottom configuration in this

passage. Two of these have been given in Fig. 27, A and B. The upper one (A) in this figure shows both above mentioned ridges ranged in echelons, leaving a passage in a direction west—east. According to detail chart 4 the greatest depth of 720 metres lies at 8°15′ S. and 130°05′ E.

On the lower one (B) a tongue-shaped depression, outlined by the 500-metre line appears,

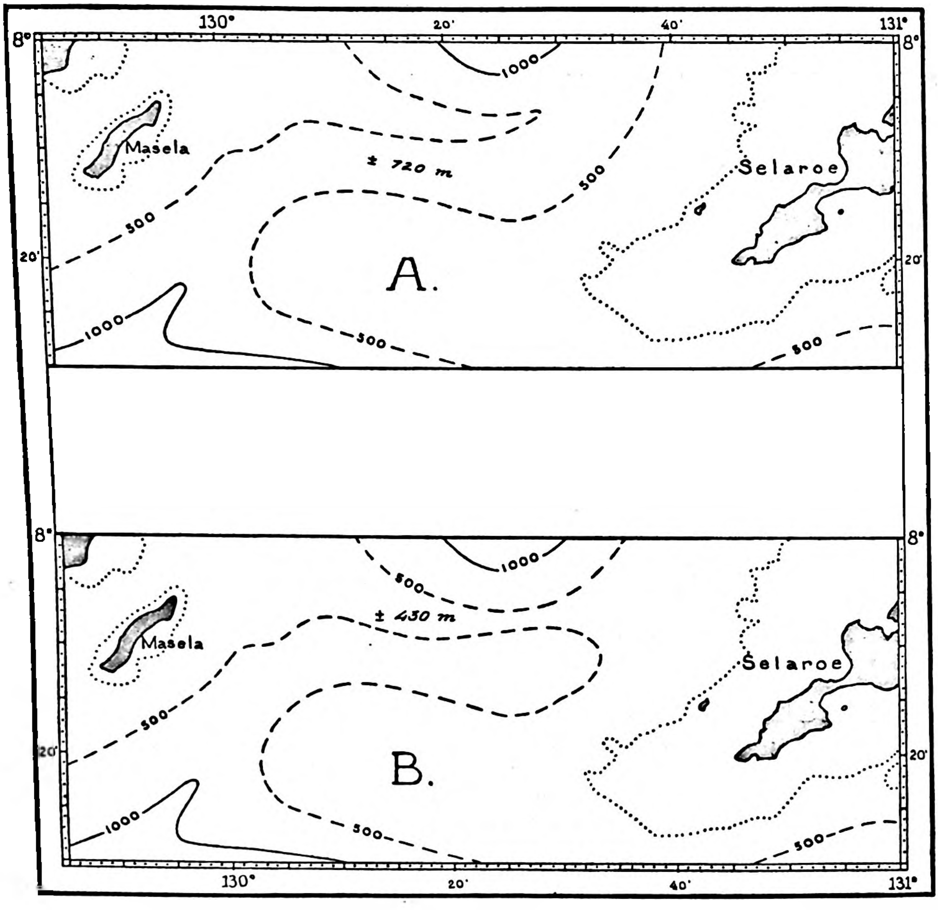

Fig. 27. Two representations of the bottom configuration in the passage between Tanimbar and Babar islands, deviating from that of the depth charts and detail chart 4.

extending from the Arafoera sea between Masela and Selaroe eastwards, leaving a ridge on which the lowest depth of about 430 metres has been recorded.

The lower part of Fig. 27 and the depth charts show a difference in maximum depth of about 300 metres with the upper part in Fig. 27. When considering the temperature and salinity distribution on both sides of the passage, it appears that concerning this point no certainty can be acquired.

In table 3 we have given the temperatures *in situ* and the salinity between 300 and 1250 metres at the stations 367 and 368 in the Weber deep and at station 112 in the Arafoera sea.

Table 3.

Comparison of temperature *in situ* and salinity between Weber deep and Arafoera sea.

Depth m	Weber deep				Arafoera sea	
	Station 367		Station 368		Station 112	
	t °C.	S ‰	t °C.	S ‰	t °C.	S ‰
300	11°.62	34.58	10°.70^5	34.58	11°.35	34.54
400	8°.96^5	.60	9°.06^5	.58	9°.20	.56
500	—	—	7°.77^5	.58	8°.20	.58
600	6°.88^5	.59	6°.78^5	.59	7°.20	.58
800	5°.72	.58^5	5°.56	.59	5°.70	.57
1000	4°.74^5	.60^5	4°.62^5	.60^5	4°.98	.58
1250	4°.04	.60^5	3°.93	.61	4°.24	.60^5

This table shows that in 400 metres the temperature gradually increases from station 367 towards station 112. In 600 metres however, the temperatures at both Weber deep stations are fairly uniform, whilst the temperatures in 500 and 600 metres are considerably higher in the Arafoera sea. This does not suggest an exchange of water across the sill at a depth of about 720 metres. The fore-going gives no evidence that the representation of the depth charts is the right one, but a choice had to be made as to the representation considered as the most probable one.

Summarizing we may conclude that, *according to the soundings,* it appears that the greatest depth in which the bottom water can enter the Aroe basin is 1600 metres. This may occur from the Ceram sea as well as from the Timor trough at the same depth.

The distribution of the properties of the sea water inside and outside the basin do not confirm this statement.

Figs. 28 and 29 show the distribution of the potential temperature and some salinity observations in vertcal sections, crossing the north-western sill in the Ceram sea and that to the east of the Tanimbar islands, which separates the Aroe basin from the Timor trough. (see Plate III).

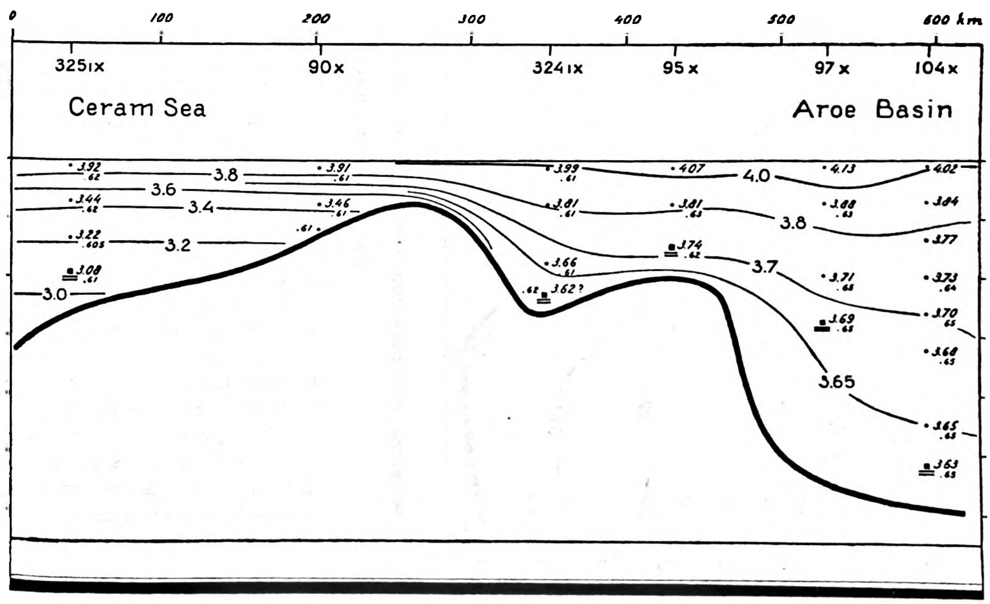

Fig. 28. Section between Ceram sea and Aroe basin. Potential temperature and salinity.

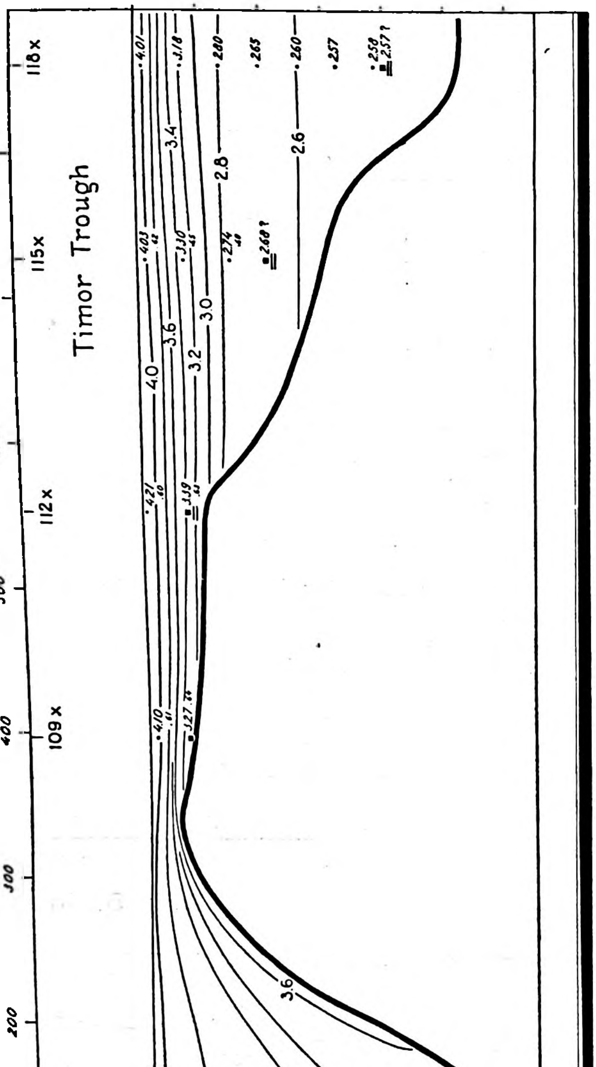

Fig. 29. Section between Timor trough and Aroe basin. Potential temperature and salinity.

In Fig. 28 the echo-soundings suggested a sill at 1600 metres between the stations 90 and 324. That a sill must occur here appears from the great difference in potential temperature at the level of 1500 metres between the stations 325 and 90, to the west, and the stations 324, 95 and 97, to the east of the sill, which are mutually in agreement.

In a local depression of the sea floor we observed at station 324 a minimum potential temperature of 3°.62 C. Though this value has been calculated from the depth and the reading of the unprotected thermometer it fits well in the vertical temperature distribution and may therefore be considered as sufficiently trustworthy.

If the sounding in 1600 metres at 3°16′ S. and 131°50′ E. indicates the position of the sill between the stations 90 and 324, the minimum potential temperature at station 324 would be less than 3°.62 C. According to the trend of the potential isotherms the saddle-depth will be about 1480 metres. A sill at this depth may be assumed at about 131°40′ E., a little to the west of the sounding at 1600 metres.

The lowest potential temperature in the Aroe basin is 3°.63 C. in the bottom layer at station 104. According to the representation in Fig. 28, this temperature may be caused by a transport of bottom water from the Ceram sea, crossing a sill at about 2000 metres near station 95. But this temperature would be accompanied by a salinity of 34.61 or 34.62 °/₀₀, whilst the bottom salinity at station 104 is 34.65 °/₀₀. This difference is too great to be ascribed to an error in the titrations as in higher levels also 34.65 °/₀₀ has been observed. Consequently we may conclude, that the bottom water in the Aroe basin does not originate from the Ceram sea.

In connection with this, Fig. 29 shows the distribution of the potential temperature and some salinity values in a vertical section across the *southern* sill between the Aroe basin and Timor trough. (see Plate III).

The soundings on the fair sheet suggest a narrow entrance at a greatest depth of about 1600 metres and the observations in the bottom layer a potential temperature of 3°.27 C. at 1465 metres [1]). As the potential bottom temperature in the Aroe basin is not lower than 3°.62 C., there must exist a shallower sill to the north of station 109 at about 7°30′ S. and, according to the trend of the potential isotherms, the depth of this sill will be about 1400 metres.

The salinity near the bottom at station 109 corresponds fairly well with that observed in the abyssal layers in the Aroe basin, with exception of that in about 2900 metres at station 100 (the bottom salinity is missing here). A closer examination of the *whole* material in horizontal and vertical sections may give an explanation of this fact.

Summarizing we may conclude for the present, *that the depth of the sill between Aroe basin and Ceram sea is about 1480 metres and that the bottom water in the Aroe basin is renewed by a transport of water from the Timor trough, crossing a sill to the east of the Tanimbar islands in a maximum depth of about 1400 metres.*

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[1]) Based on the average of wire- and echo-depth, which differ only 14 metres.

C. THE NATURE OF THE SEA FLOOR

The nature of the sea floor will be dealt with in another chapter when discussing the flow of the bottom water and the properties of the sea water in the bottom layer.

For the present we will confine ourselves to mentioning the fact that in nearly all passages leading to the different basins and troughs, a hard bottom of sand, pieces of coral, gravel, small stones and rock detrites with a coating of manganese have been observed, even at great depths.

That the normal sedimentation is not found in these entrances must be attributed to the considerable velocity of the sill-current, which renews the abyssal layers in the partly closed basins.

Tydeman draws attention to this possibility (Bibl. 21, p. 115) when discussing the four wire soundings taken during the Siboga-expedition in Lifamatola strait, the principal passage between the Molukken sea and the Ceram sea.

D. SUMMARY OF THE PRINCIPAL RESULTS

The number of soundings, available before 1929, was inadequate to draw a sufficiently reliable representation of the sea floor in the eastern part of the Archipelago. During the Snellius-expedition this number has been increased from about 3500 to 35.000.

Based on this material one large depth chart, I (in two sheets) and 16 detail charts have been drawn, referring to this eastern part; a depth chart II, embracing the whole Archipelago, has been added to this chapter.

Notwithstanding this considerable increase of data, the available soundings in several parts appeared to be inadequate to the complexity of the sea floor. In such cases the drawing of the contours of depth produced difficulties, as different representations were possible. Some of these cases have been discussed here and more may be discovered by carefully studying the large number of soundings plotted on chart I and the detail charts. The representation shown on the charts is also based on oceanographic and geological considerations.

In the foregoing pages the configuration of the sea floor has been discussed from an oceanographic standpoint. As the properties of the abyssal waters in the partly closed basins depend on those of the water outside at a depth equal to that of the deepest entrance, much attention has been paid to the determination of these.

A comparison of the present charts with previous ones, shows the advance in our knowledge of the topography of the sea floor in the regions investigated.

As a summary of the principal features of the bottom configuration in the eastern part of the Archipelago, a general view has been given on Plate IV of the most important basins and troughs. The Roman figures refer to column 1 of Table 4, p. 56. Below these figures have been printed the greatest depth recorded in the basin[1]) and the depth of its deepest entrance. On the same chart lines have been drawn, connecting the deepest entrances of the successive basins, according to soundings and oceanographic data. The arrows show the direction of the flow of the bottom water and give an idea of the part which the Pacific and Indian Ocean and the China sea play in the renewal of the abyssal layers in the isolated basins. When discussing the flow of the bottom water, this subject will be treated more extensively.

In Table 4 some particulars may be found concerning the basins. The Roman figures in column 1 refer to Plate IV; column 2 contains the names of the basins, outlined by the contours of depth mentioned in column 3; the area within this depth in square kilometres has been added in column 4. Columns 5 and 6 show the depth of the deepest entrance and the deepest recorded sounding in metres and columns 7 and 8 contain the minimum temperature *in situ* in degrees Celsius and the salinity in thousandths, both observed in the depth printed underneath at stations lying in the centre of the basin or in the axis of the trough.

When the minimum temperature has been observed at more than one station in the same basin, depths and salinities have been averaged. These minimum temperatures have not been derived from temperature-curves but are the actual values observed.

To furnish a clear image of the connection between the various larger and smaller islands at a depth of 2000 metres, a separate representation has been given on Plate V of the sea floor at this depth[2]).

[1]) On Plate IV, Celebes sea, has been printed 6200 instead of 6220.

[2]) For the names of the islands see depth chart I.

Table 4. Basins and troughs in the eastern part of the Indian Archipelago.

Nr.	Name	Limit	Area (square kilo-metres)	Saddle-depth (metres)	Greatest depth (metres)	Min. temp. °C. in situ	Salinity ‰
I	Sulu basin	4000	46000	400[1])	5580	10°.07^5 1225	34.49 1225
II	Mindanao trough	6000	—	—	10830	1°.55^5 3490	34.63 3490
III	Talaud trough	3000	2700	3130	3450	—	—
IV	Sangihe trough	3000	10000	2050[2])	3820	2°.39^5 2550	34.64^5 2550
V	Celebes basin	4000	260000	1400	6220	3°.57^5 2475	34.56 2475
VI	Morotai basin	3000	6500	2340[2])	3890	1°.81 2490	34.65 2490
VII	Ternate trough	3000	1000	2710	3450	1°.85 2761	34.67 2761
VIII	Batjan basin	3000	6800	2550	4810	2°.06 2970	34.66 2970
IX	Mangole basin	3000	1900	2710	3510	—	—
X	Gorontalo basin	3000	14000	2700	4180	2°.19^5 2740	34.63 2740
XI	Makassar trough	2000	55000	2300[1])	2540	3°.59 2133	34.58 1990
XII	Halmahera basin	1000	15000	700	2039	7°.75^5 1839	34.60 1839
XIII	Boeroe basin	3000	16000	1880	5319	3°.02^5 3240	34.61 3240
XIV	Northern Banda basin	4000	80000	3130	5800	3°.04 2990	34.62 2990 [3])
XV	Southern Banda basin	4000	120000	3130	5400	3°.06 2720	34.60 2720
XVI	Weber deep	4000	50000	3130	7440	3°.07 2990	34.61 2990
XVII	Manipa basin	3000	2800	3100	4360	3°.10^5 3185	34.60^5 3185
XVIII	Ambalaoe basin	4000	7000	3130	5330	3°.08^5 3235	34.61 3235 [3])
XIX	Aroe basin	3000	11000	1480	3680	3°.89^5 2240	34.65 2240
XX	Boetoeng trough	4000	1200	3130	4180	—	—
XXI	Salajar trough	2000	4000	1350	3370	3°.86^5 1750	34.60^5 1750
XXII	Flores basin	3000	30000	2450	5130	3°.22^5 2480	34.61 2480
XXIII	Bali basin	1000	19000	—	1590	3°.57^5 1488	34.61 1488
XXIV	Sawoe basin	3000	30000	2100	3470	3°.39 2360	34.61 2360 [3])
XXV	Wetar basin	3000	6000	2400	3460	3°.16^5 2500	34.61 2500
XXVI	Timor trough	2000	30000	1940	3310	2°.67 2254	34.71 2254
XXVII	Java trough	6000	—	—	7140	1°.17^5 4230	34.71 4230

[1]) Approximately.
[2]) Direct connection with the Pacific Ocean.
[3]) Mean value of two stations.

The connection of Celebes with Borneo and Java and the Asiatic-shelf appears distinctly on this chart, whilst the floor, sloping from the Australian-shelf to a similar depth, embraces the Tanimbar, Kai and Aroe groups, the islands of Ceram, Boeroe, New-Guinea and Halmahera and the Aroe and Halmahera basins.

The Australian part is connected in the south with the row of the Lesser Soenda islands by a ridge, bearing Timor, Roti, Sawoe and Soemba, and isolating the Timor trough. In the north the narrow ridge, extending from Lifamatola strait towards the west and bearing the Soela and Banggai groups, establishes a connection of the eastern part with Celebes.

The Palawan and Sulu ridges connect Borneo with the Philippines; the Sangihe ridge connects the Philippines with Celebes.

As the most important new features, we draw attention to the rise of the floor to the east of the Talaud islands; the elongated wide central ridges, extending to the south of this group; the rise observed to the south of the island Boeroe and the interruption of the Siboga ridge (which previously has been regarded as one elongated ridge) situated to the south of the island Ceram.

On Plate VI a representation is given of the configuration of the sea floor at 4000 metres, which reveals clearly the deepest parts of our field of research.

In the north-east lies an isolated part of the deep Pacific Ocean with the still deeper Mindanao trough to the west, in which a depth of over 10800 metres has been observed. This extreme western part is separated from the open ocean by a ridge, extending between New-Guinea and Japan of which the most southern part appears on the depth charts.

In the Indian Ocean lies the deep Java trough, separated from the row of islands by an elongated rise of the sea floor followed by a second depression, all three extending in a direction west—east.

Between the two oceans three large and deep basins are situated: The Sulu basin, the Celebes basin and the Banda basin. The latter is divided into three portions, namely the northern and southern basin and the Weber deep, mutually connected to a depth of over 4000 metres. Between the southern and northern basin appears a wide rise, ranging from the Toekangbesi islands to Ceram of which the bottom configuration is very irregular.

The floor in the above mentioned basins, in contrast with this, is fairly level. The abrupt rises which appear on Plate VI in the centre of the Sulu basin and in the western part of the Celebes sea are based on single previous wire soundings, which have not been confirmed by other soundings in the vicinity. Though the existence of these rises is doubtful, the soundings have been maintained on the chart. The same holds good for a submarine volcano at 4° N. and 124° E., which was reported in 1922.

A smaller basin should be mentioned to the north of the island Flores, and the Ambalaoe and Boeroe basin to the south and north of the island Boeroe. To the south-east of the island Celebes lies the small Boetoeng trough.

In the Molukken sea only the deepest portions are shown of the Gorontalo and Batjan basins. The remaining shallower basins and troughs disappear on this chart.

In the Pacific Ocean we draw attention to the rise of the sea floor to the east of Mindanao and to the north-east of Halmahera, which were unknown hitherto.

E. FUTURE INVESTIGATIONS

Though the number of soundings have been increased considerably during the expedition, there remain several regions, where additional soundings are highly desirable. This may appear at a glance from depth chart I, on which the track of the ship can be easily followed, in the regions where data are scarce, by the successive soundings.

Of these regions we mention particularly:

The southern and eastern part of the Celebes sea.

The entrance to Makassar strait, where the fixing of the ship's position may not always have been sufficiently accurate and the floor seems to be very irregular.

The southern part of the Molukken sea.

The north-western part of the Banda sea.

The region to the east of the Toekangbesi islands.

The north-eastern part of the Aroe basin and its northern and southern entrances.

The eastern part of the Timor trough.

The region to the north of New-Guinea, to ascertain whether the southern extension of the Mindanao trough bends towards the east in the vicinity of Halmahera and runs to the north of the Asia islands, along the coast of New-Guinea at a depth of about 4000 metres [1]).

If additional data could be collected by ships equipped with an echo-sounding apparatus travelling in these regions, valuable information might be acquired, without the expenditure of much money.

By making use of similar opportunities the Netherlands Navy would add to the great assistance already given during the expedition, and further the completion of the depth chart, principally based on soundings taken by H.M.S. "Willebrord Snellius", during the expedition.

[1]) See appendix, p. 59.

APPENDIX

After the depth charts and part of the text had gone through the press the author received the corrected proofs of the echo-soundings, made during the Dana-expedition. I am much indebted to Dr. Å. V. Tâning and Dr. H. Thomsen, members of this expedition, for putting these data at my disposal as soon as possible.

The apparatus used during the cruise was an Atlas echo-sounding apparatus, Type II, with automatic recording device for depth up to 180 metres. No corrections have been applied to the readings. For further information we refer to the "Dana"-reports.

The soundings, based on a constant velocity of 1500 metres per second, have been corrected by me for the exact mean velocity which had been calculated beforehand and appeared to deviate only slightly from those published in: "Tables of the velocity of sound in pure water and sea water for use in echo-sounding and soundranging. Hydrographic Department, Admiralty, London, 1927."

The "Dana" crossed the region of the Pacific Ocean twice, appearing on the depth charts and lying between 1° S. and 5° N. As especially in this area the "Snellius"-data are scarce, some soundings were plotted on the track along the north coast of New-Guinea and along the parallel of about 4° N. to improve the representation on the charts. This has been done in Fig. 30.

The rise of the sea floor, lying east of Morotai at about 2° 30′ N. and 129° 40′ E., the depth of which has been recorded as 1990 m, is probably connected with a rise at about 3° 50′ N. and 129° 30′ E.

A second, shallower spot (2069 metres) observed by the "Dana" on the northern track at about 131° 10′ E. suggests a second narrow ridge, on the southern extension of which lies the island of Tobi. This second ridge may be part of a narrow elongated ridge, limited by the depth contour of 3000 metres which connects New-Guinea with the Palao islands along Ajoe Is., Anna Is., Tobi, the soundings 2069 and 2579 and Sonsorol Is. and separates the Mariana basin from the Caroline basin.

Between Merir island and Helen Reef the "Dana"-soundings show a passage at a depth of at least 3342 metres. The depression to the east of Merir island may be a continuation of the deep Palao trough.

As may appear from Fig. 30 the contours of depth have been drawn as far as possible in a north—south direction in correspondence with the trend of the depth contours in the extreme western part of the Ocean.

According to the additional soundings north of New-Guinea a connection probably exists between the Asia Is. and Waigeo. The deep tongue between them and outlined by the 1000-metre line, may be regarded as a continuation of the deep depression which probably runs north of New-Guinea.

Though the soundings of the "Dana" enabled us to improve the representation of the bottom configuration as appearing on the depth charts in the region shown in Fig. 30, there is still no certainty as to the greatest depth of the ridge connecting Palao island with New-Guinea.

Together with the echo-soundings of the "Dana" Dr. Thomsen kindly put at my disposal the temperature and salinity data of station 3751. These data have been placed side by side with those of "Snellius"-station 275 in table 5 for comparison. Beside the temperature *in situ* the potential temperature Θ, referring to the surface, has been given in this table.

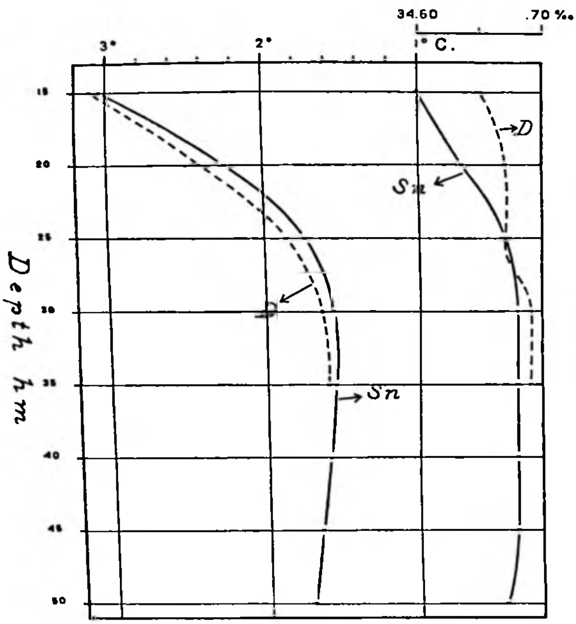

Fig. 31. Temperature *in situ* and salinity at „Snellius"-station 275 and „Dana"-station 3751.

Table 5. Comparison of temperature and salinity data in Mariana and Caroline basins.

Depth m	"Sn." St. 275			"Dana" St. 3751		
	t_1°C.	Θ_1	S_1‰	t_2°C.	Θ_2°C.	S_2‰
1000	4.46	4.38	34.53	4.68	4.60	34.61
1200	3.83	3.74	.58⁵	3.90	3.81	.63
1500	3.05	2.94	.60	3.10	2.99	.65
2000	2.25	2.11	.63⁵	2.40	2.25	.67
2500	1.74	1.56	.67	1.86	1.68	.67
3000	1.56	1.34	.68	1.65	1.42	.69
3500	1.55	1.27	.68	1.60	1.32	.69
4000	1.59	1.26	.68			
4500	1.65	1.25	.68			
5000	1.71	1.25	.67			

"Snellius"-station 275 lies in the Mariana basin in the southern extension of the Mindanao trough at 2° 53'.0 N. and 129° 13'.5 E. "Dana"-station 3751 is situated in the western part of the Caroline basin.

According to the representation printed on the back of the Pilot Chart of the Indian Ocean January 1932, this basin is bounded by the 2000-fathom line (3660 metres) and has a narrow entrance at 6° N. and 153° E. between the Truk and Nomoi Is. at a depth of about 2200 fathoms (4026 metres).

This means that the Caroline basin is in direct horizontal connection with the open Ocean up to this depth so that a comparison of the properties of the sea water in this basin with those in the Mariana basin may shed some light on the question of the greatest depth of the dividing ridge: Palao—New-Guinea.

Most unfortunately however no data below a depth of 3500 metres of "Dana"-station 3751 are available.

Table 5 and Fig. 31 show that the salinities at both stations differ only slightly at a depth of 2500 metres; in higher levels the differences increase. The temperature *in situ* in the Caroline basin (St. 3751) is little higher than that in the Mariana basin (St. 275). Here the minimum temperature *in situ* has been observed at a depth of 3500 metres and the decrease of the potential temperature between 3000 and 3500 metres of 0°.07 C. per 500 metres suddenly drops to 0°.01 C. between 3500 and 4000 metres.

The decrease of the temperature *in situ* at station 3751 between 3000 and 3500 metres is greater than at station 275, so that the dotted temperature-curve in Fig. 31 approaches the full drawn line in this level. This may point to the fact that the minimum temperature *in situ* in the Caroline basin has not yet been attained at a depth of 3500 metres, which would suggest a dividing ridge between the two stations in about 3000 to 3500 metres.

The data are however too uncertain for any definite conclusion to be founded on them as to the deepest connection between the Mariana and Caroline basins and we must content ourselves with the improvements shown in Fig. 30 and acquired by the additional echo-soundings of the "Dana". Further investigations will undoubtedly show, that the bottom configuration in this part of the Pacific Ocean is much more complicated than hitherto supposed.

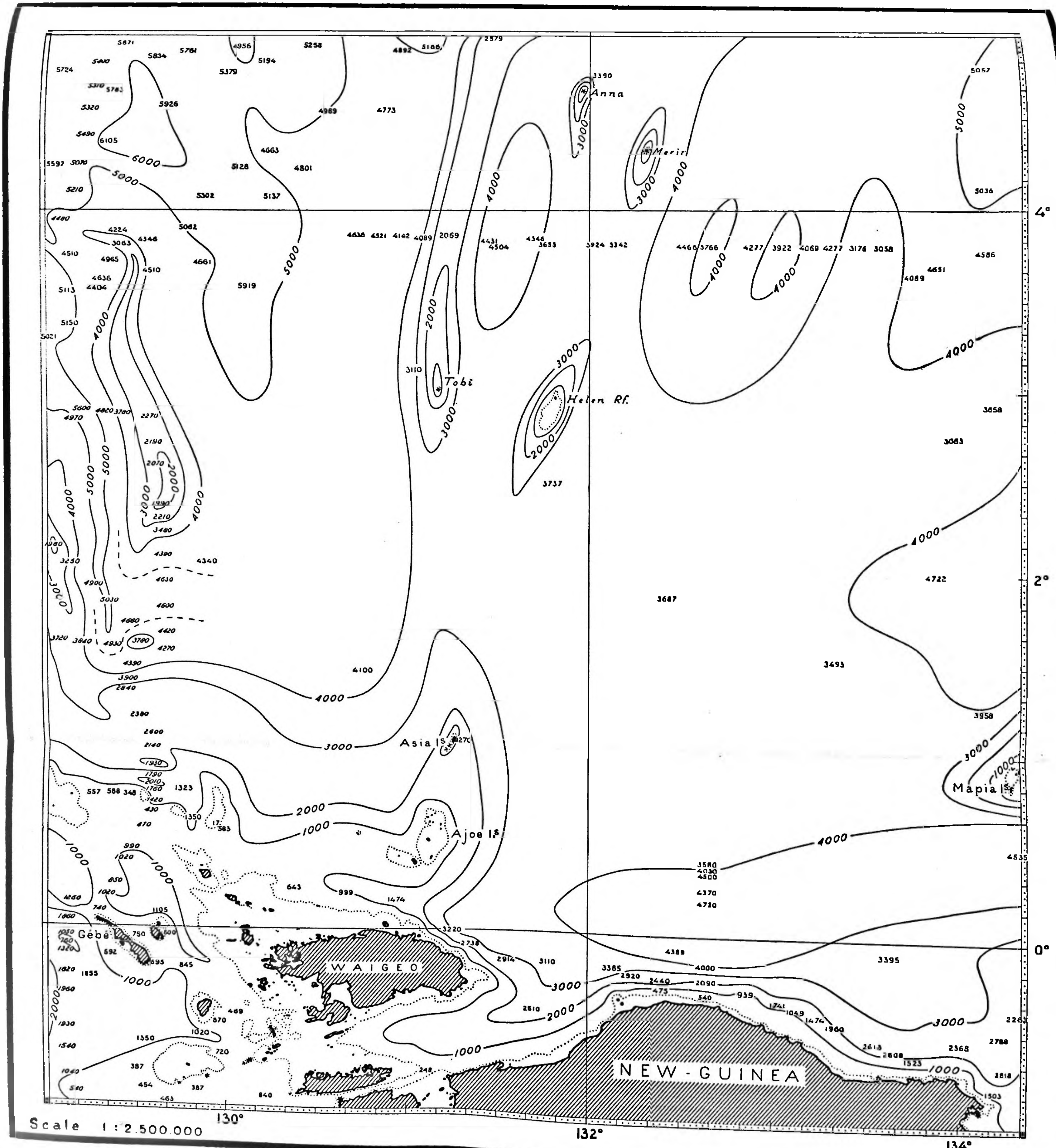

Fig. 30. Improved respresentation of the bottom configuration in the Pacific Ocean.

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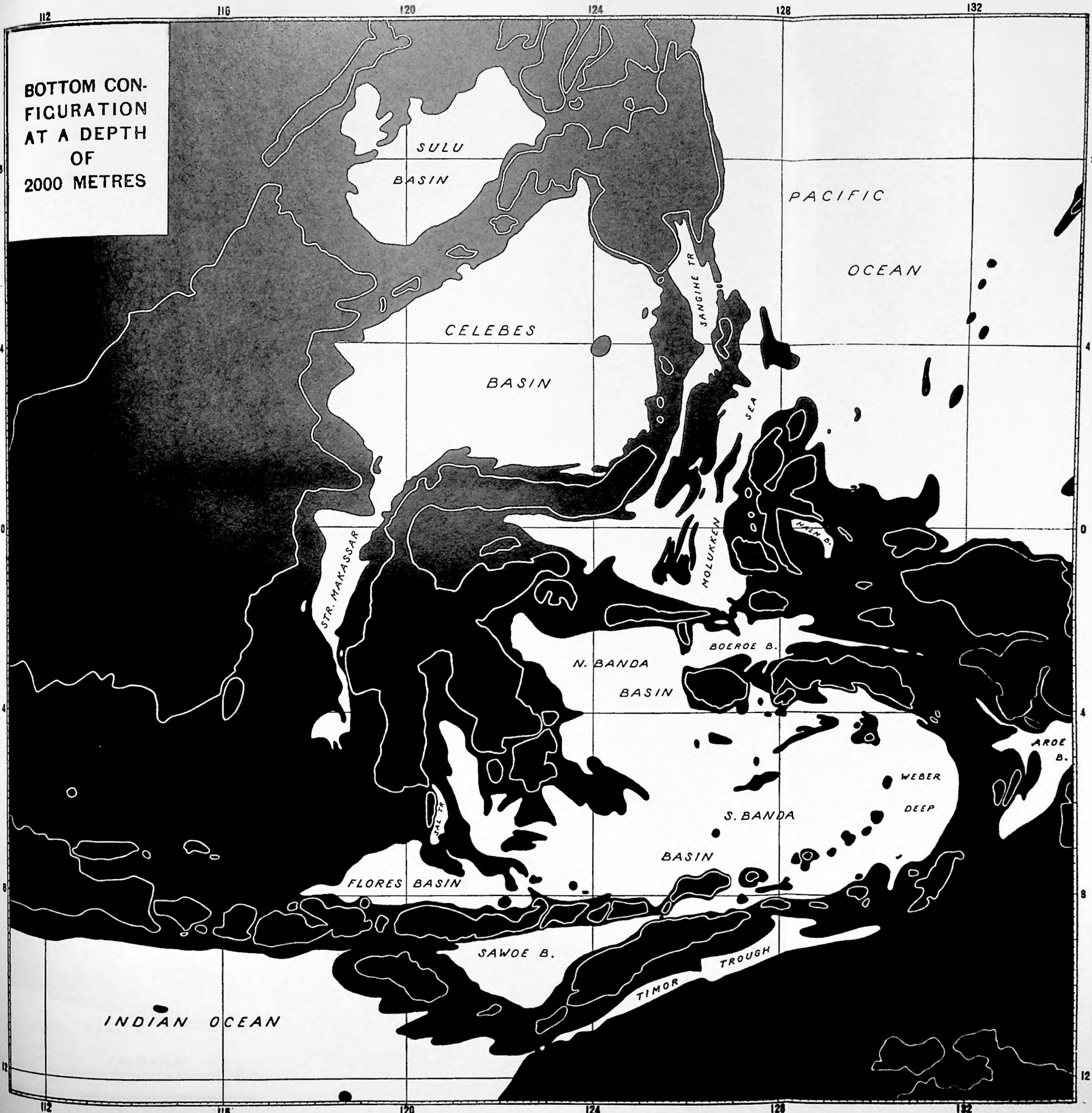
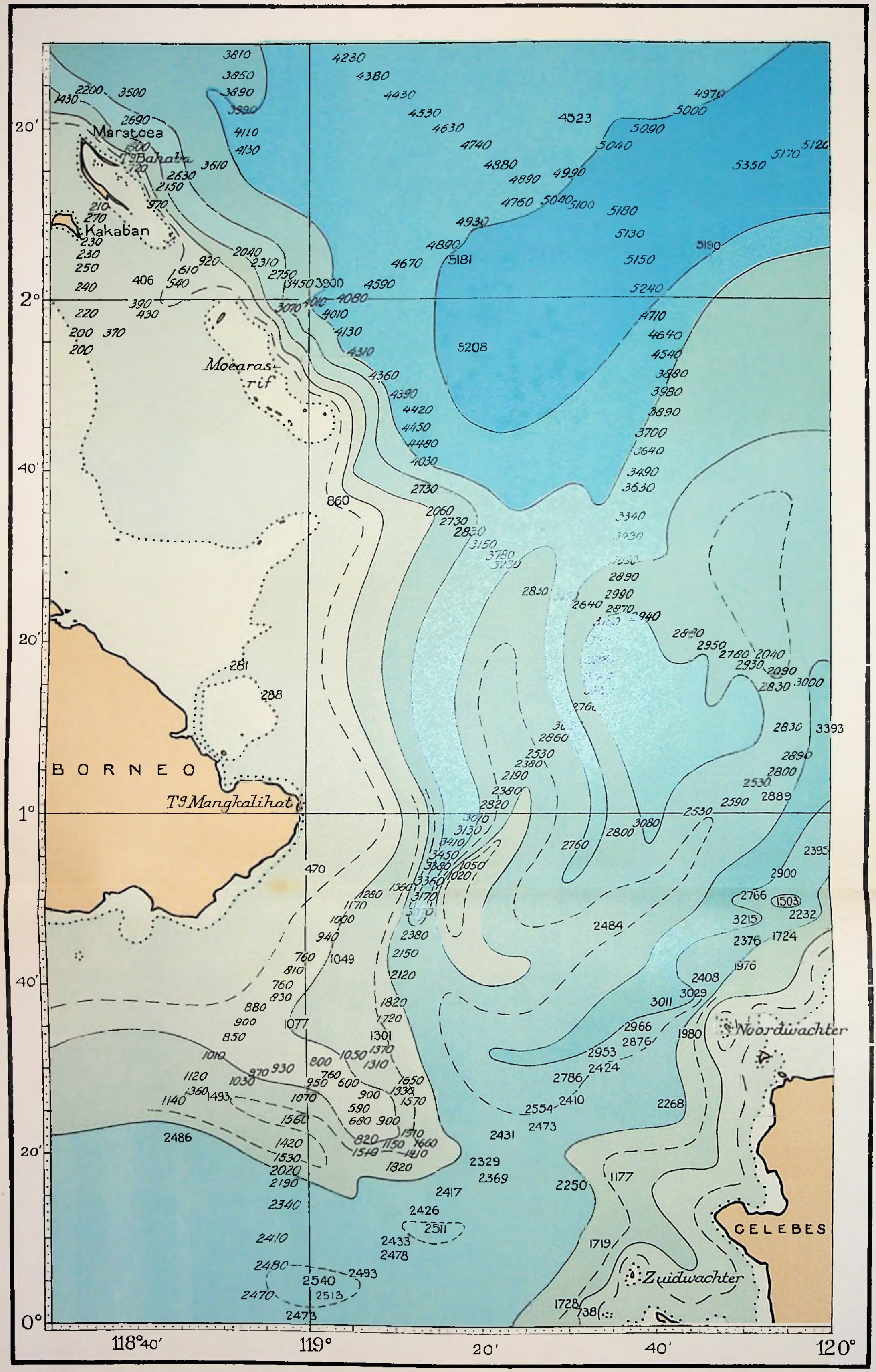
Scale 1 : 6.500.000.


BOTTOM CONFIGURATION AT A DEPTH OF 2000 METRES
112
116
120
124
128
132
SULU
BASIN
PACIFIC
OCEAN
CELEBES
BASIN
SANGIHE TR
SEA
MOLUKKEN
HALM. B.
STR. MAKASSAR
BOEROE B.
N. BANDA
BASIN
AROE
B.
WEBER
DEEP
S. BANDA
BASIN
SAL TR
FLORES BASIN
SAWOE B.
TIMOR
TROUGH
INDIAN OCEAN
8
4
0
4
8
12


BOTTOM CONFIGURATION AT A DEPTH OF 4000 METRES
SULU BASIN
CELEBES BASIN
MINDANAO TROUGH
PACIFIC OCEAN
BATJAN C.
BOEROE B.
N. BANDA BASIN
WEBER DEEP
S. BANDA BASIN
FLORES B.
JAVA TROUGH
INDIAN OCEAN
112
116
120
124
128
132
8
4
0
4
8
12



Top. Dienst 1934.

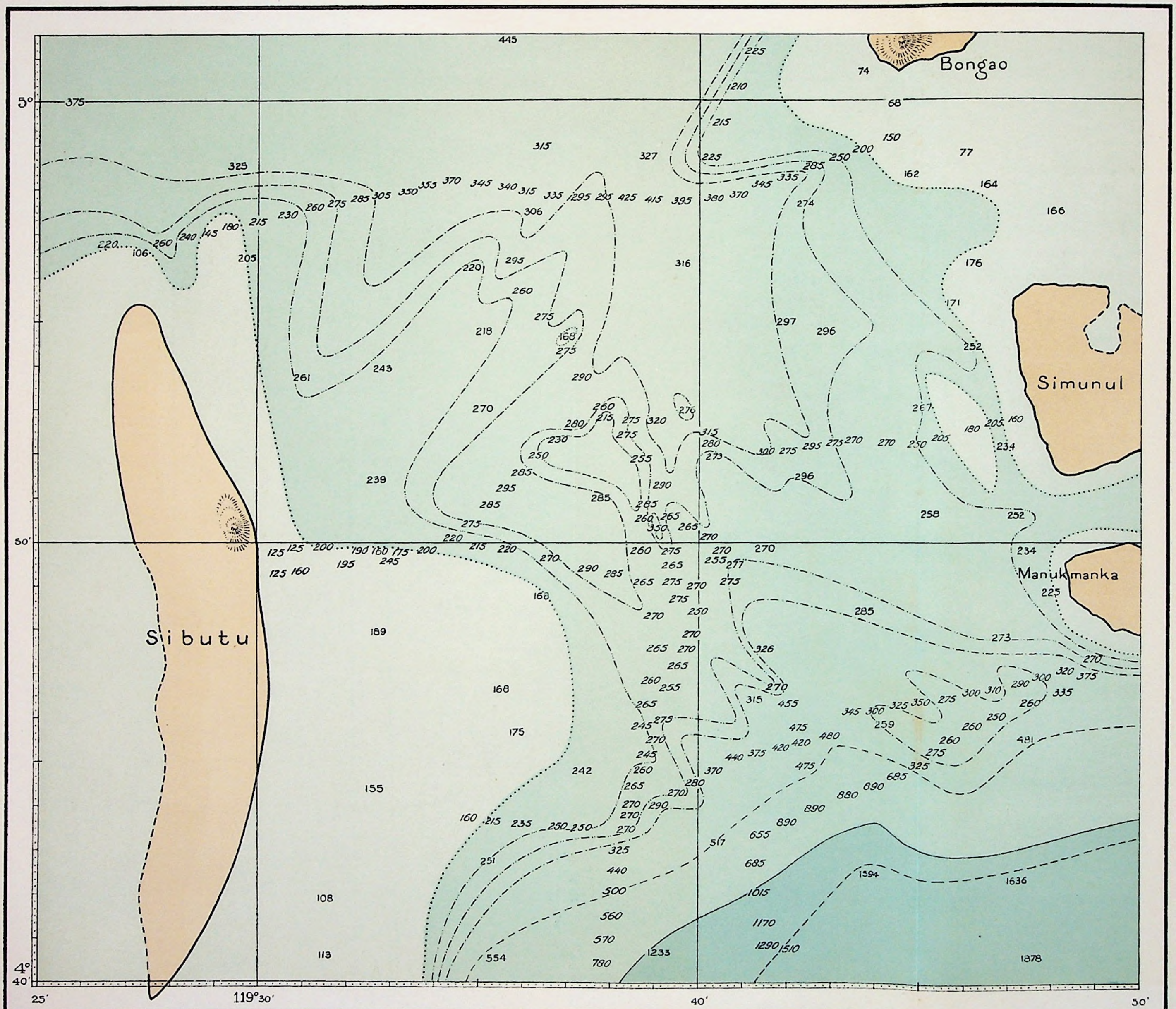
Foto-litho

1. NOORDELIJKE TOEGANG TOT STRAAT MAKASSAR

NORTHERN ENTRANCE TO MAKASSAR STRAIT

10 0 10 20 30 40 50 km.

1 : 1.000.000



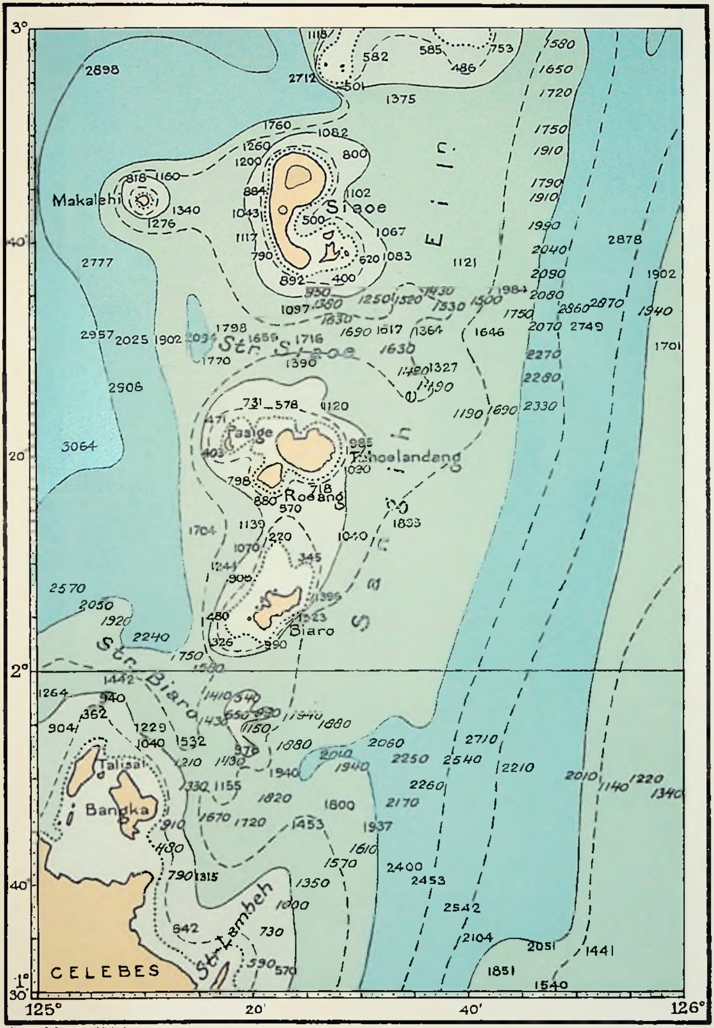
Top. Dienst 1934.

2. STRAAT SIBUTU SIBUTU PASSAGE

Foto-litho

2 1 0 2 4 6 8 10 km

1 : 200.000

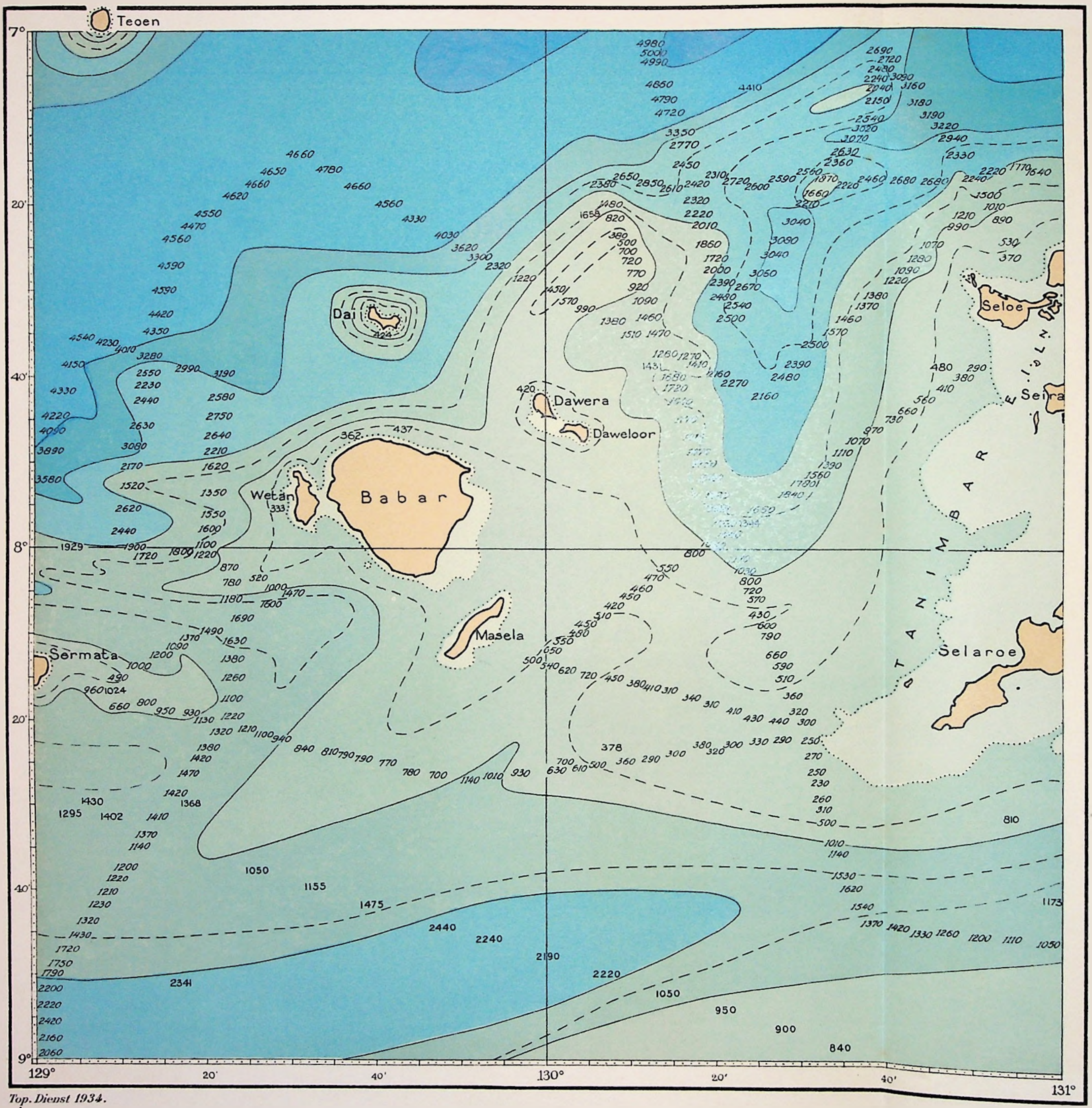


Top. Dienst 1934. *Foto-litho*

3. STRATEN TUSSCHEN N. PUNT CELEBES EN SIAOE
PASSAGES BETWEEN N.E. CELEBES AND SIAOE I.

10 0 10 20 30 40 50 km

1 : 1.000.000



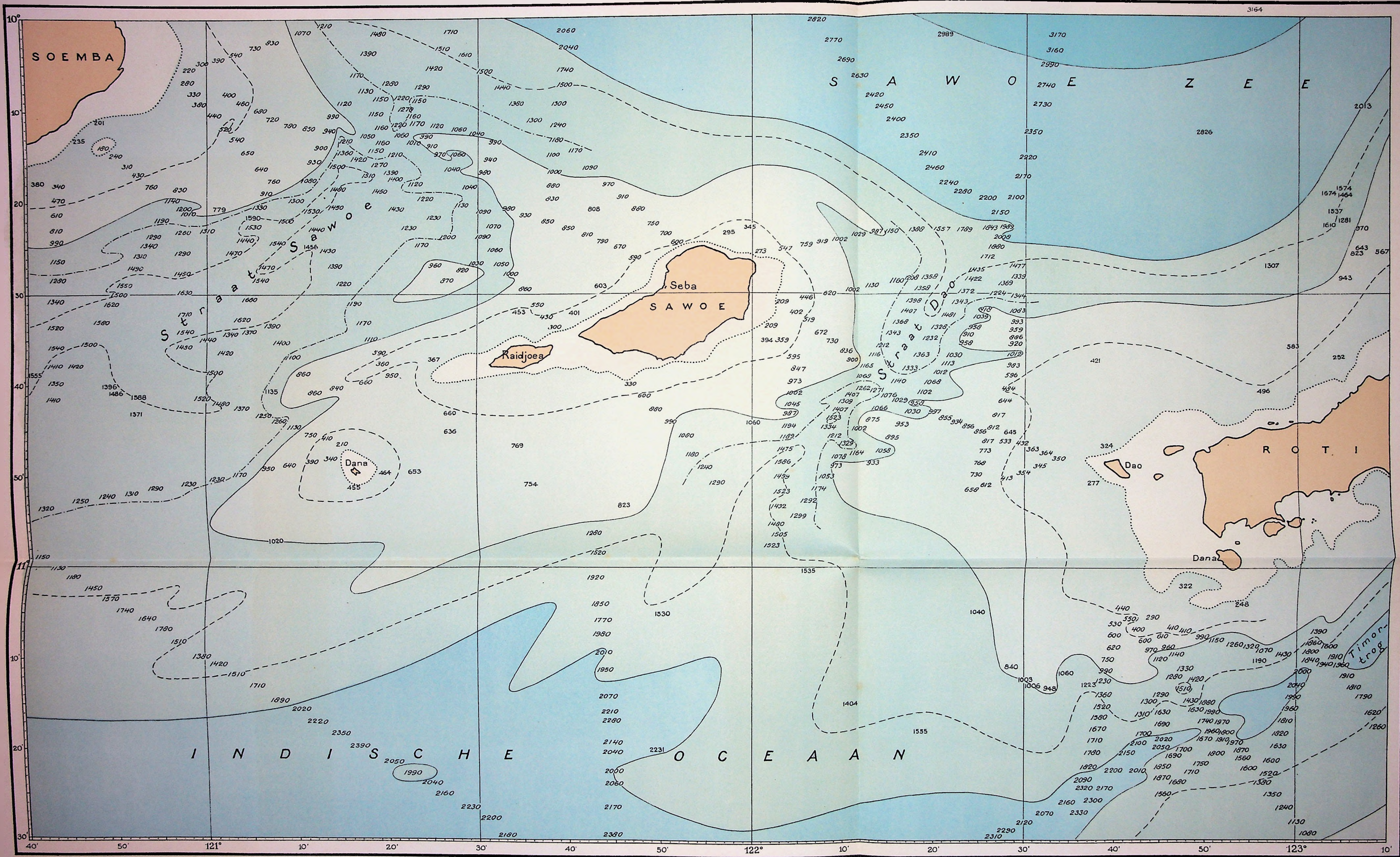
Top. Dienst 1934.

4. DOORGANG TUSSCHEN TANIMBAR-EILN EN BABAR   PASSAGE BETWEEN TANIMBAR IS AND BABAR I.

Foto-litho

10 0 10 20 30 40 50 km

1 : 1000.000



Top. Dienst 1934.

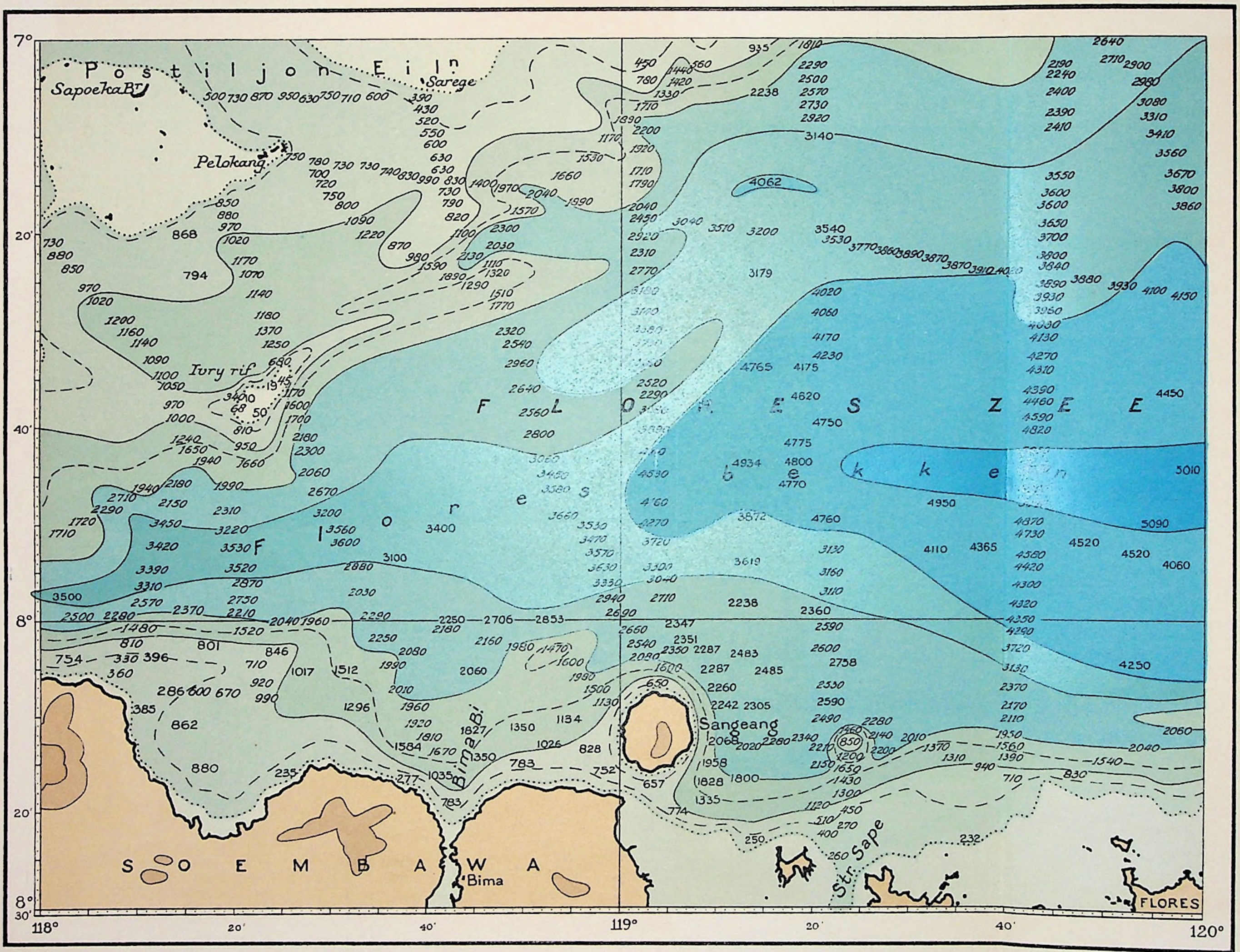
Foto-litho

5. ZUIDELIJKE TOEGANGEN TOT SAWOE ZEE EN TIMOR TROG

SOUTHERN ENTRANCES TO SAWOE SEA AND TIMOR TROUGH

5 0 5 10 15 20 25 km

1 : 600.000



Top. Dienst 1934.

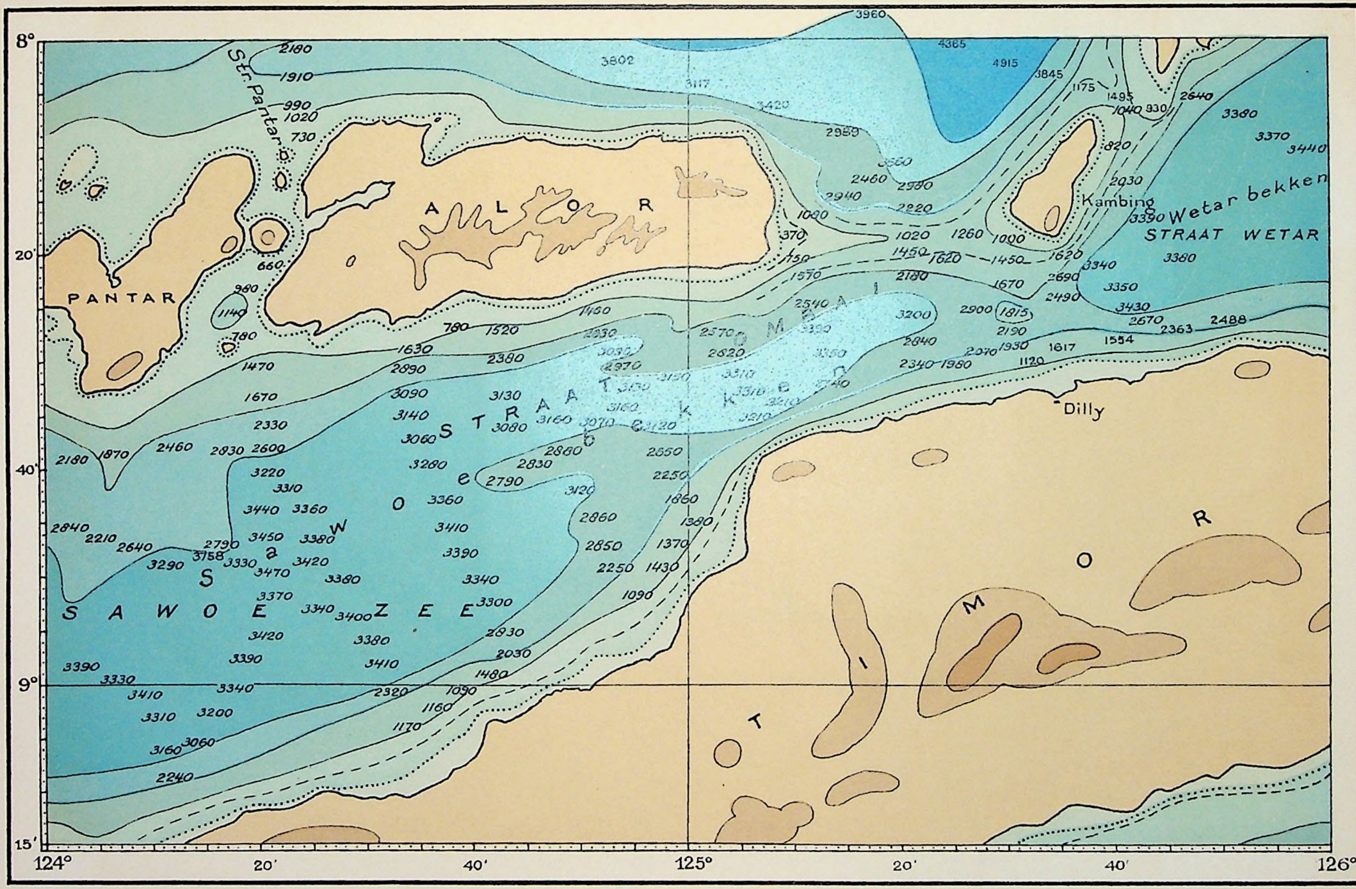
6. WEST FLORES ZEE

WESTERN PART OF THE FLORES SEA

Foto-litho

10 0 10 20 30 40 50 km

1 : 1.000.000

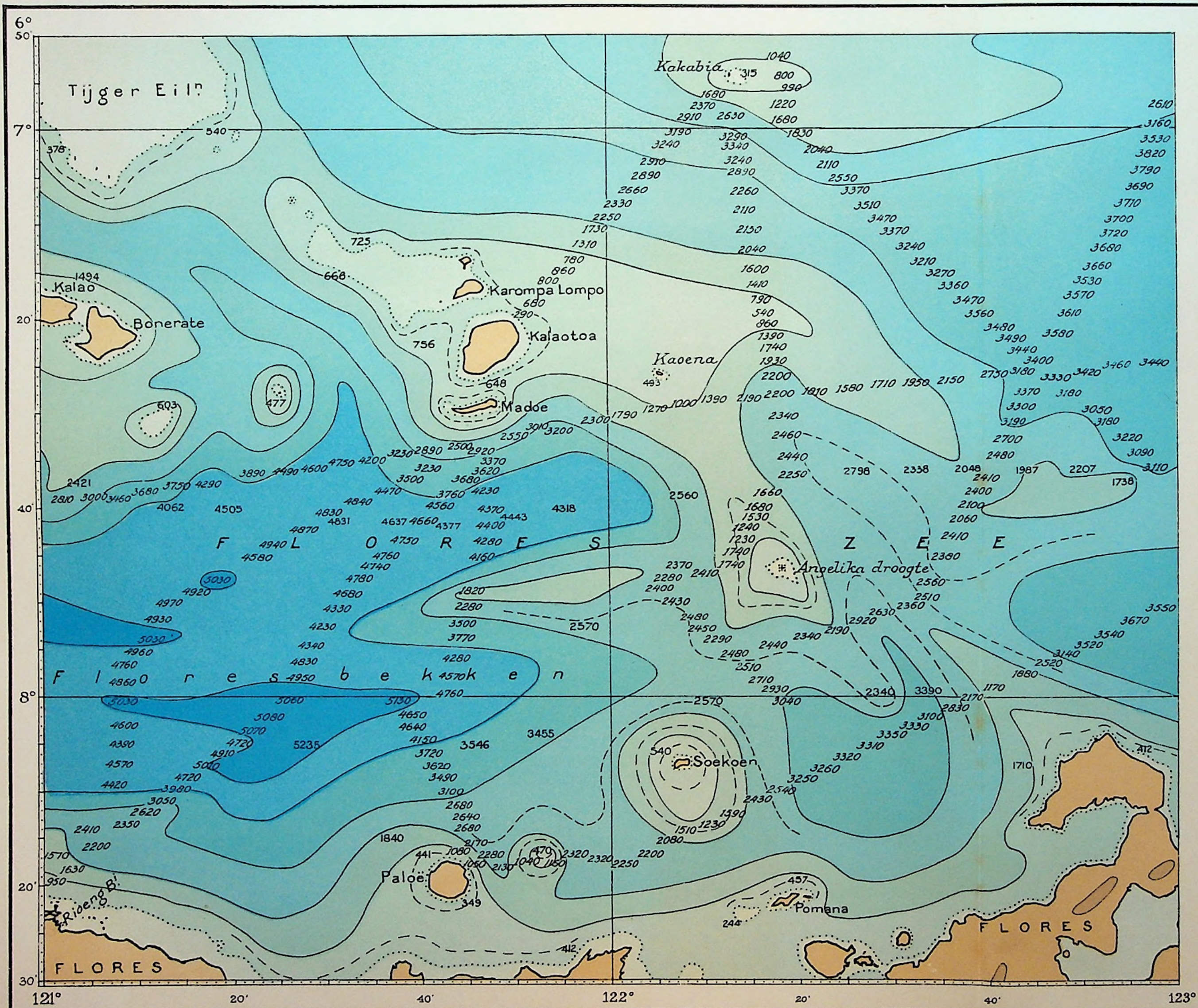


Top. Dienst 1934. Foto-litho

7. STRAAT OMBAI OMBAI PASSAGE

10 0 10 20 30 40 50 km

1 : 1.000.000



Top. Dienst 1934. Foto-litho

8. OOST FLORES ZEE EASTERN PART OF THE FLORES SEA

10 0 10 20 30 40 50 km

1 : 1.000 000

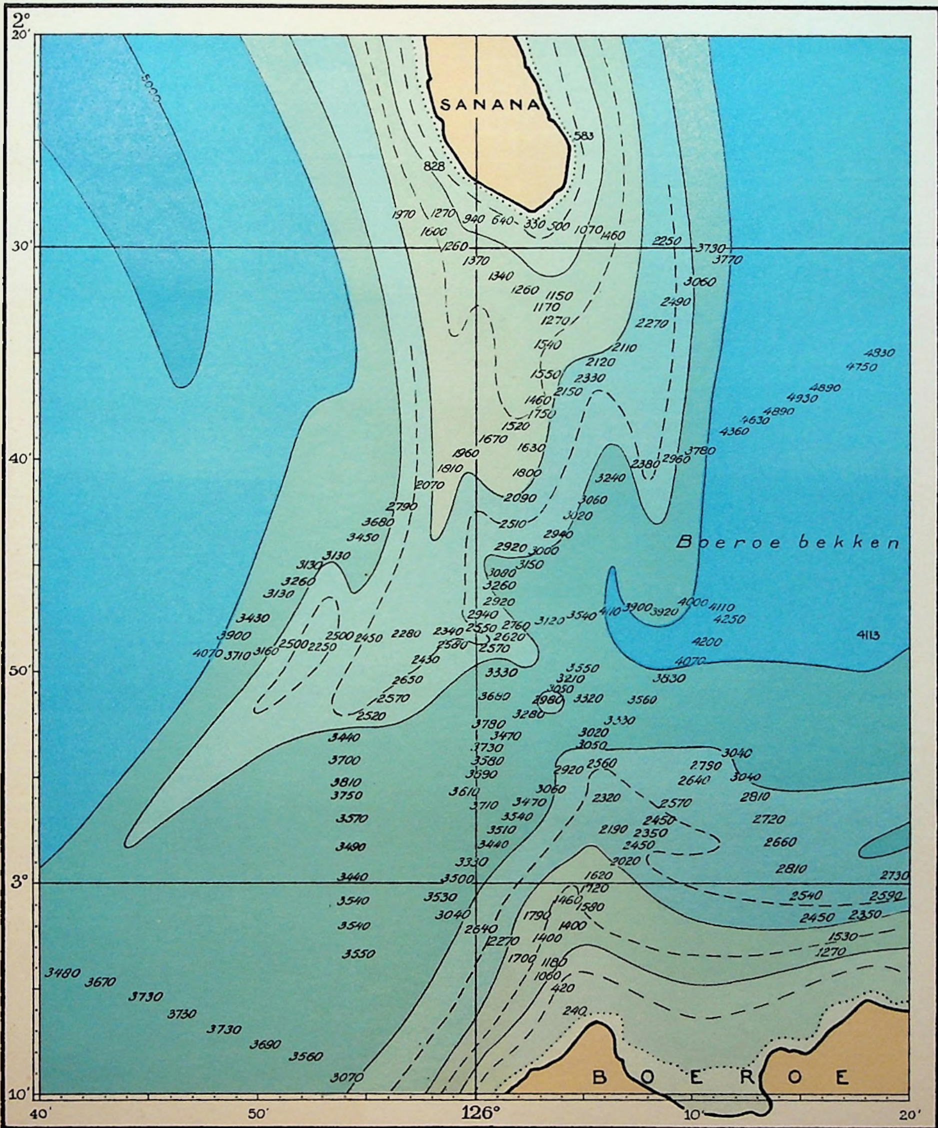
Top. Dienst 1934.

Foto-litho

9. TOEKANGBESI - EILANDEN (ISLANDS)

10 0 10 20 30 40 50 km

1 : 1.000.000



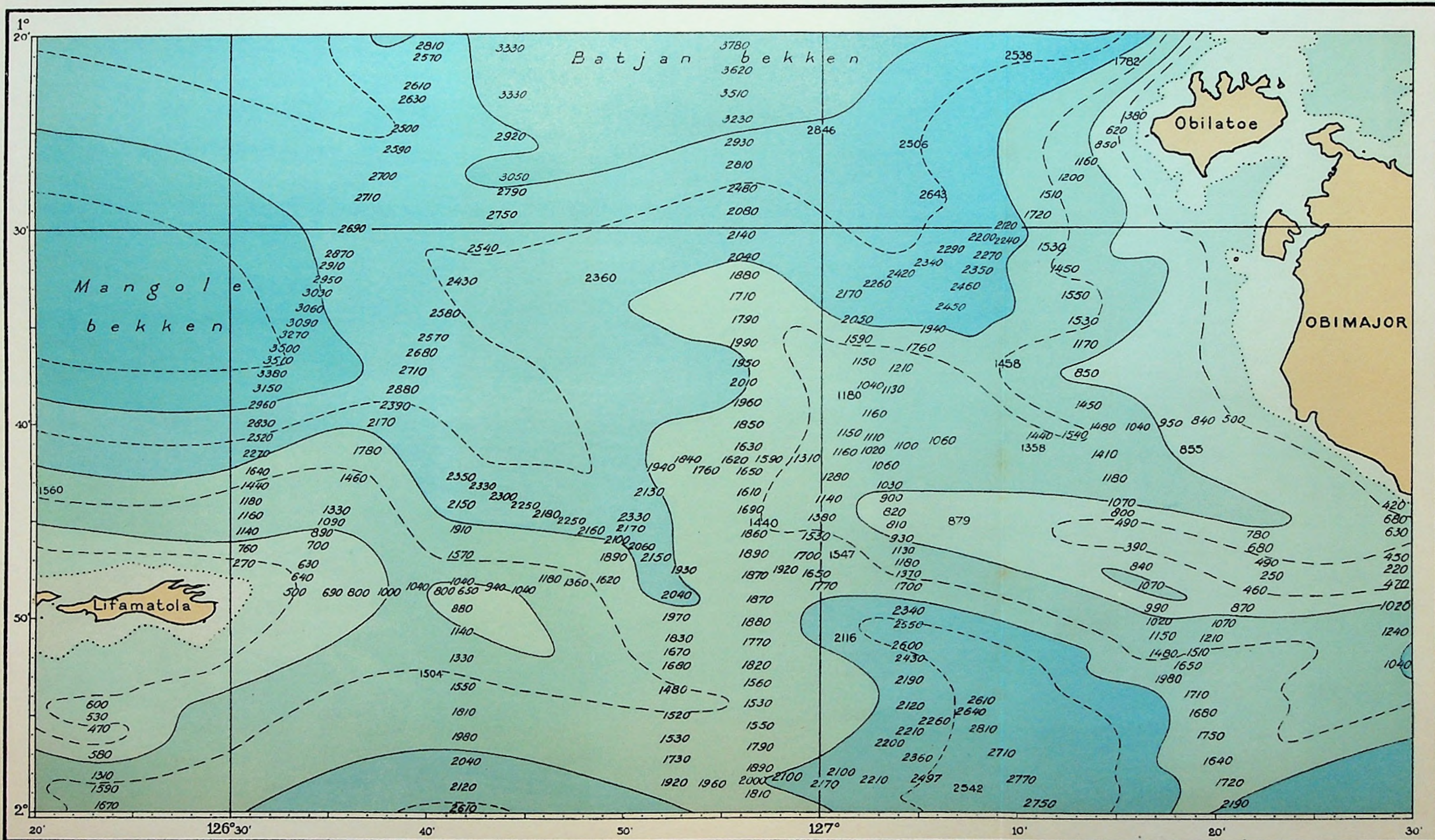
Top. Dienst 1934.

Foto-litho

10. DOORGANG TUSSCHEN BOEROE EN SANANA
PASSAGE BETWEEN BOEROE AND SANANA

5 0 5 10 15 20 25 km

1 : 500000



Top. Dienst 1934.

Foto-litho

11. STRAAT LIFAMATOLA 1:500000 LIFAMATOLA STRAIT

5 0 5 10 15 20 25 km

Top. Dienst 1934.

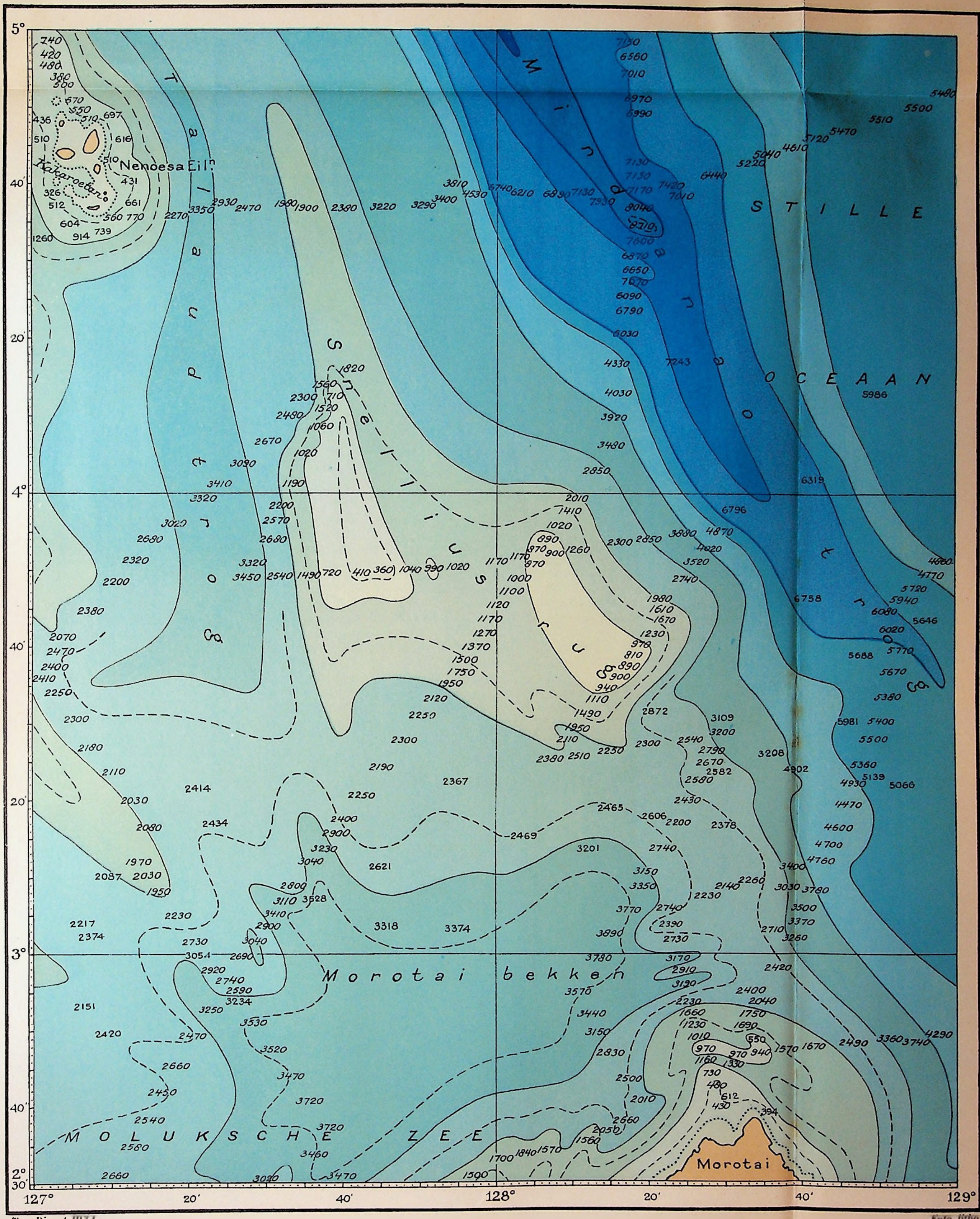
Foto-litho

12. STRAAT MANIPA

MANIPA STRAIT

5 0 5 10 15 20 25 km

1 : 500.000

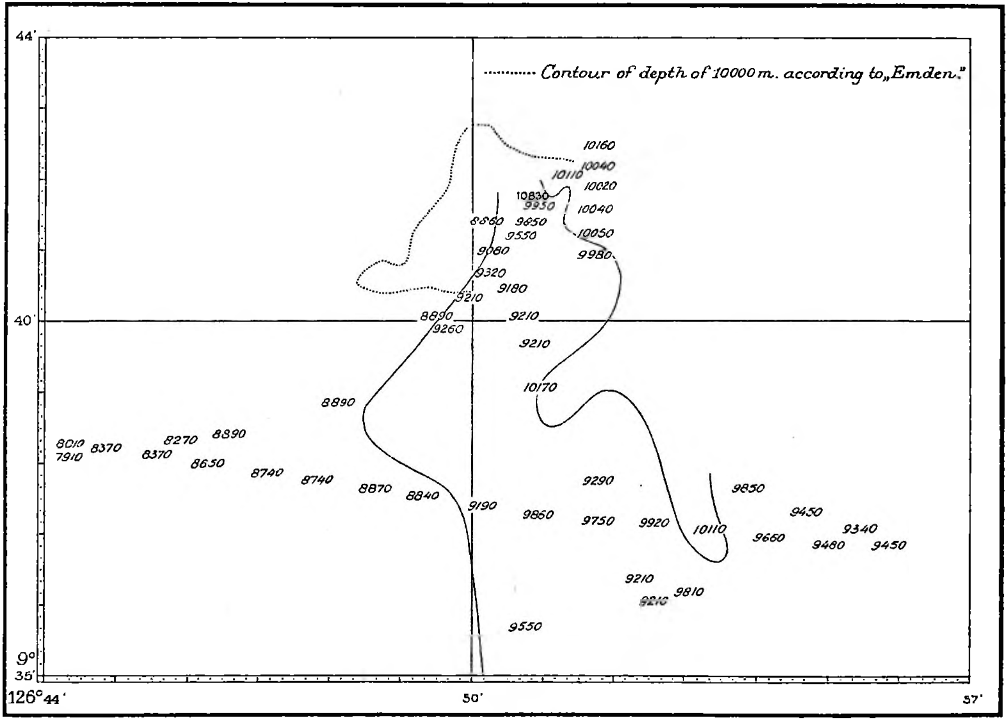


13. TOEGANG VAN DEN STILLEN OCEAAN TOT DE MOLUKSCHE ZEE

ENTRANCE TO THE MOLUKKEN SEA

10 0 10 20 30 40 50 km

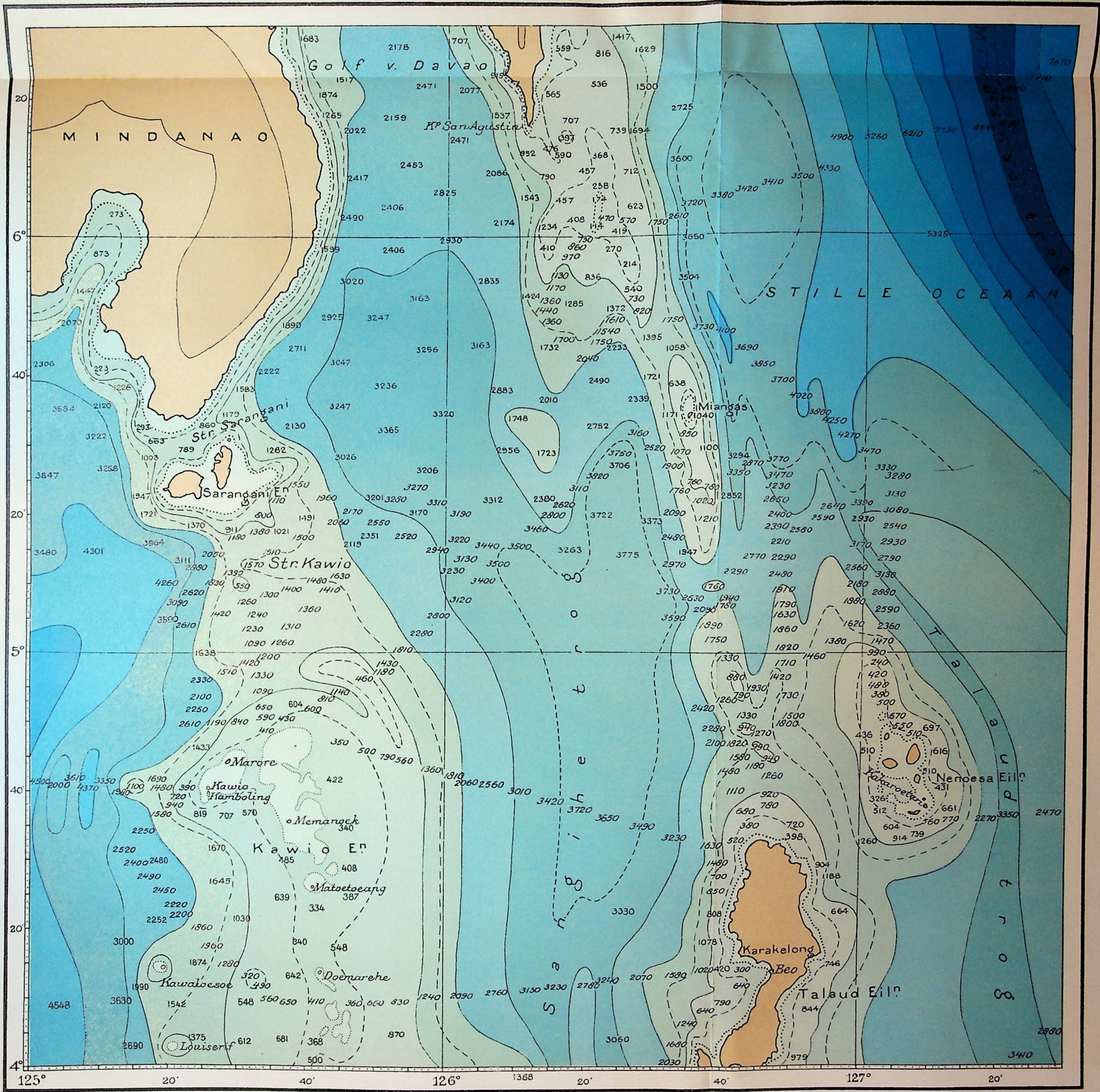
1 : 1.000.000



Top. Dienst 1934. Foto-litho

14. MINDANAO TROG MINDANAO TROUGH
(naar F. Pinke)

1 0 1 2 3 4 5 6 km
1 : 150.000



Top. Dienst 1934.

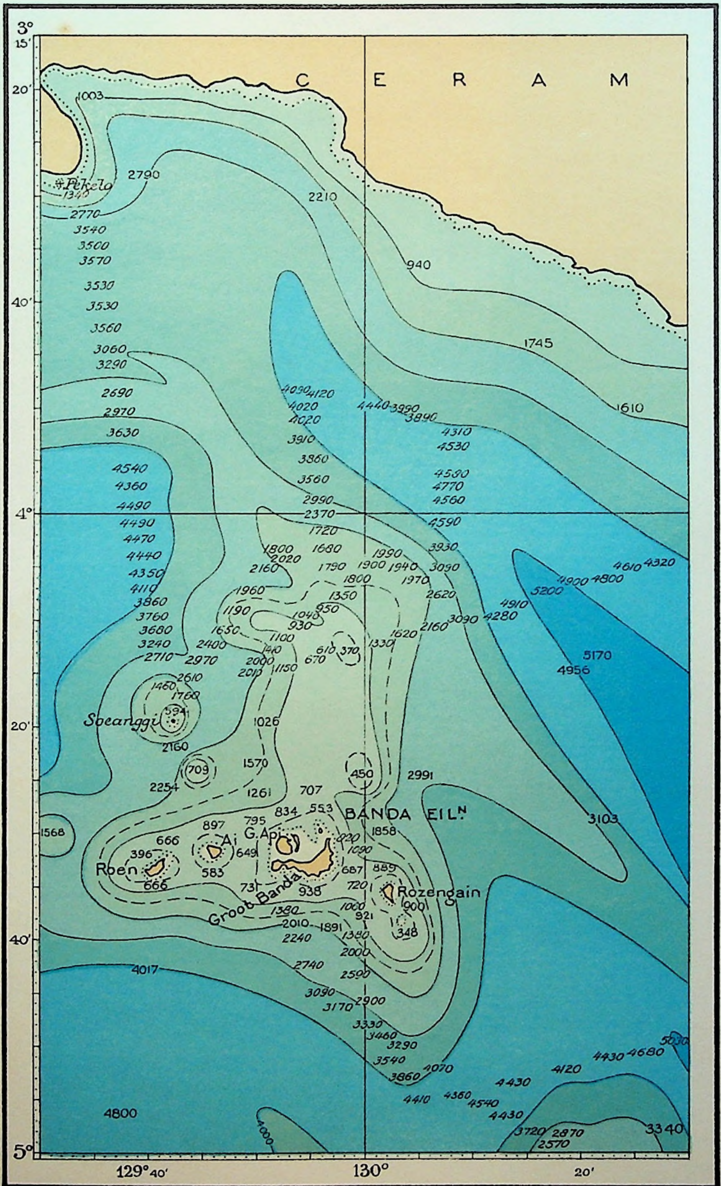
Foto-litho

15. STRATEN BEZUIDEN MINDANAO

ENTRANCES TO THE CELEBES SEA

10 0 10 20 30 40 50 km

1 : 1.000.000



Top. Dienst 1934.

Foto-litho

16. BANDA PLATEAU

10 0 10 20 30 km

1 : 1.000.000


CELEBES
Kleine Paternoster Eil.
SPERMONDE
ARCHIPEL
MAKASSAR
Moena
Toekangbesi Eil.
BANGGAI
ARCHIPEL
SOELA EILANDEN
BOEROE
NIEUW-GUINEE
J A V A Z E E
B A N D A Z E E
MADOERA
SOERABAJA
Straat Madoera
J A V A
BALI ZEE
BALI
LOMBOK
Kangean Eil.
Postiljon Eil.
Paternoster Eil.
WETAR
TANIMBAR EIL.
A R A F O E R A Z E E
S O E M B A W A
F L O R E S
S A W O E Z E E
S O E M B A
T I M O R
T I M O R Z E E
Koepang
I N D I S C H E O C E A A N
A U S T R A L I Ë
113° E.L. Greenwich
114°
116°
118°
120°
122°
124°
126°
128°
130°
132°
134°

Plaat I

DIEPTEKAART VAN HET OOSTELIJKE GEDEELTE VAN DEN OOST-INDISCHEN ARCHIPEL

HOOFDZAKELIJK VOLGENS LOODINGEN VAN DE „SNELLIUS"-EXPEDITIE

ONDER LEIDING VAN P.M. VAN RIEL

1929 - 1930

COMMANDANT VAN H.M. „WILLEBRORD SNELLIUS" F. PINKE

Schaal 1:2 500 000

BATHYMETRIC CHART OF THE EASTERN PART OF THE EAST INDIAN ARCHIPELAGO

CHIEFLY FROM SOUNDINGS BY THE „SNELLIUS"-EXPEDITION

UNDER LEADERSHIP OF P.M. VAN RIEL

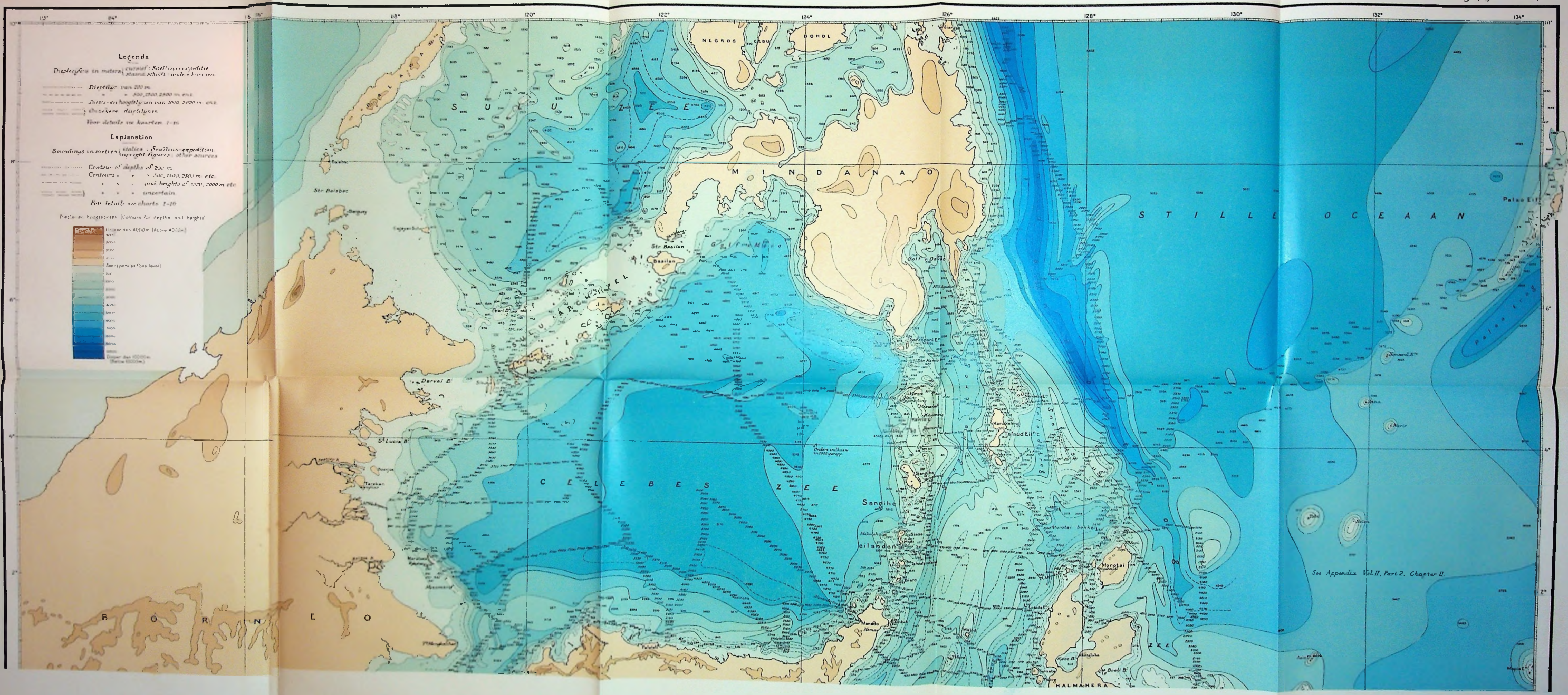
1929 - 1930

COMMANDER OF H.M.S. „WILLEBRORD SNELLIUS" F. PINKE

Scale 1:2 500 000

Plate I

Snellius-Expedition Vol.II, Oceanography, Part 2, Chapter II



DIEPTEKAART VAN DEN OOST-INDISCHEN ARCHIPEL
BATHYMETRIC CHART OF THE EAST-INDIAN ARCHIPELAGO